

SUPPLEMENTAL REPORT

Effect of Federal Structures on Adjacent Shore Lines

Providence, Rhode Island, District

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EFFECT OF FEDERAL STRUCTURES ON ADJACENT
SHORE LINES

PROVIDENCE, RHODE ISLAND, DISTRICT

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Fantucket Harbor, Massachusetts

1. Conditions prior to construction of jetties. - The tidal inlet at Nantucket has been the subject of reports since 1829. The report of 1829 advocated dredging a channel through the bars. A map dated 1828 shows a proposed channel 17 feet deep at low water. It was believed that a dredged channel would be self-maintaining without jetty protection. The outer bars were described as consisting of compact sand 1 foot deep, underlaid by hard blue clay, and the inner bars showed sand 6 feet deep, the extent of the boring. Controlling depth of 6 feet at low water was shown on the map. The dredging required was 46,150 cubic yards, estimated to cost \$11,500. This yardage was probably based on a channel width of about 150 feet. In the basis of the 1829 report, appropriation was made for the work, and \$14,365 was expended during 1830, 1831, and 1832. The volume removed and the size of the channel temporarily secured by this expenditure are not stated. However, no sooner did it occur, one storm nearly filling up the channel as far as dredged. Records do not show any further attempt to improve the entrance without jetties. The total expenditure prior to adoption of the existing project was \$15,734.75.

2. Tidal Survey. - A tide table for Nantucket Island printed in Executive Document No. 18, 46th Congress, 2d Session, and Annual Report of Chief of Engineers for 1880, Appendix B, pages 423 to 436, gives mean

tidal ranges as follows: Grant Point, 3.07 feet; Commercial wharf (Narragansett Harbor), 3.00 feet; and head of harbor, inside of Pawtuxet Beach, 3.17 feet. Pawtuxet Beach is a narrow strip of sand separating the head of the harbor from the ocean on the east side of the island. The same document shows two sets of curves taken on each side of Pawtuxet Beach in 1874. In November and December, 1938, three rises and four falls were observed at Head of the harbor. By comparison with simultaneous observations inside Grant Point, a mean range of 3.3 feet was derived for the head of the harbor, or about the same as the range in the ocean at Pawtuxet, just south of Pawtuxet Beach, as given by the Coast and Geodetic Survey Tide Tables for 1939. The subject is discussed by Professor Henry Stetson in a report to the Superintendent of the United States Coast Survey, printed in the appendix of the ninth annual report of the Board of Harbor Commissioners of Massachusetts for the year 1871. Their report for 1872 is also said to contain pertinent data. These reports are not on hand in this office. The mean range of tide at Narragansett as determined by the Coast and Geodetic Survey from three months' records in 1934, reduced to mean values, is 3.00 feet. That outside the jetties may be slightly greater.

5. Tidal prism. - The Annual Report of the Chief of Engineers for 1935, Appendix I, page 565, gives a figure for the mean volume of the tidal prism of about 573,000,000 cubic feet, based upon the coverage of the ranges of tide at four stations in the tidal basin (given as 2.) feet).

and the area of the basin (given as 132,451,009 square feet at half tide). Almost 4,000 feet of the western jetty were completed at the time. It is not likely that this construction had any material effect on the tidal prism. The cross-sectional area between Brant and Coatus Points is given as 24,500 square feet, but the elevation to which this was taken is not stated. From the 1874 and 1934 surveys, half-tide level cross-section areas of 21,500 and 20,700 square feet respectively were determined. Current velocities were observed on December 29, 1938, for computation of the tidal prism. Velocities were observed at thirteen stations along a line starting near the shore end of the east jetty and extending southwestward normal to the current direction. Stations were spaced 100 feet apart in the deeper water and 300 feet apart in shallow water. Observations were made at 0.6 depth at each station at intervals varying from about 1/4 to 1/2 hour. Rates of discharge computed from each observation were plotted. The resulting discharge curves were fairly complete for each station throughout the tidal cycle between two low water slack. The summation of the inflow and outflow volumes for the thirteen stations gave total inflow and outflow for the cycle of 440,000,000 and 420,000,000 cubic feet respectively. The range of tide was 2.15 feet on the rise and 2.12 feet on the fall at the metering line. The average inflow or outflow for these ranges may, therefore, be assumed as 430,000,000 cubic feet, and in proportion, the inflow and outflow for the mean range of tide would be about 610,000,000 cubic feet. The cross-sectional areas of the metering section were 21,200

square feet at mean low water, 14,700 square feet at half tide level and 20,500 square feet at mean high water.

4. Jetty construction. - The first project for jetty construction was adopted in 1880 and provided for the west jetty 6,500 feet in length of large riprap stone. This project was based on report of 1879 printed in Executive Document No. 13, 46th Congress, 2d Session. An east jetty was to be built later if the western one failed to secure by tidal scour the increased depth sought (12 to 14 feet). Dredging to obtain desired depth was not contemplated. Work on the west jetty was commenced in April, 1881, and continued as appropriations were received until 3,755 feet were completed in August, 1881.

5. In 1881 erosion occurred on the north side of Brant Point immediately east of this jetty. To arrest this, short spurs were built at right angles to the jetty on its east side from near its shore end out for 150 feet. These spurs resulted in deposition of sand and advance of the shore line. During the year six other spurs were built on the west and south sides in continuation to arrest erosion of its shore. The location of these spurs is shown on the revised drawing No. A. H. M. 256. In 1884 chipstone was placed in the section of the west jetty which had been too loosely built. Subsequently smaller stones were incorporated in new work and resulted in a tighter jetty.

6. Due to the fact that the completed portion of the west jetty had failed to effect any material increase in the navigable depth over

the outer bar, the plan of improvement was revised in 1895. Under the new plan a location and design for an eastern jetty was adopted, and a 15-foot channel was to be obtained by dredging, if necessary. The outer end of the west jetty was realigned to the westward so as to reach the 15-foot contour with about 1,000 feet less length. The east jetty was to have the same trapezoidal full section as the west jetty for the inner shore 2,500 feet, thence was to have a half-tide section. It was to extend to the 15-foot contour, a distance of about 7,000 feet. Work on the west jetty was to be suspended and the east jetty begun.

7. Construction of the east jetty began in April 1896 and continued in accordance with the revised plan. It was completed in full section to a length of 834 feet by June 30, 1896. In 1892 it was decided to build up a considerable length of the east jetty to half-tide level before completing it to full cross section. This was due to the fact that scour around the end of the jetty developed and made it necessary to build in 15 feet of water instead of in 5 feet. After leaving a gap of 160 feet, 1,000 feet of the east jetty was built to half-tide level during the Fiscal Year 1892. No addition was made during Fiscal Year 1893. Work on the east jetty was continued as appropriations were received. By September, 1896, the condition was reported as follows: "The east jetty had been built up to its full height for a length of 2 $\frac{1}{2}$ feet from the shore end, then the foundation laid for a length of 172 feet, then came a gap of 160 feet, then 1,300 feet raised to half-tide level, then 2,145 feet raised

to 1.5 feet below low-tide level, and the remaining distance of 210 feet (the total length from the shore end being 4340 feet) raised to 1.5 feet below mean low water, and a mound of heavy stone built to protect a lantern staff near the present end of the jetty." No work had been done to lengthen the west jetty. It had, however, been strengthened and leveled up at points where it had settled.

8. Although only 120 feet of the east jetty had been completed to June 30, 1886, it was reported that "on a line from Brent Point to the present end of the west jetty the least depth of water was nearly 1-1/2 feet greater than at the time of our previous survey," By June 30, 1894, a channel depth of 3 feet by tidal scour was reported.

9. In December 1896, during an unusually severe storm, a breach was made between the ocean and the head of the harbor at Haulover Beach. It apparently caused no perceptible change in the depth of water at the harbor entrance, but to avoid narrowing that entrance while the breachway was open, work on the east jetty was suspended and that on the west jetty resumed. Accordingly from June to September, 1897, an extension of the west jetty by about 1,000 feet was built to the level of 1.5 feet below mean low water.

10. Work was resumed in July to December, 1899, and in May, 1900. The submerged portion of the east jetty was raised to half-tide level, 600 feet of the outer end of the west jetty was raised to the full height and 400 feet to half-tide level, and repairs were made to the shore end

of the east jetty. No construction was in progress during Fiscal Years 1901, -02, -03. In June and July 1904 the gap in the east jetty was filled to the elevation of mean low water. From June to August, 1905, a 1379-foot extension of the east jetty was constructed to the elevation of half-tide with buoys every 200 feet to mark its location, and from May to September, 1907, it was further extended 768 feet at the same elevation to its present end, a distance of 6967 feet. During the latter period about 1,300 foot of the east jetty across Denton Flats was raised to 5 feet above mean low water.

11. Original dredging. - Despite the completion of the west jetty approximately to its present dimensions in 1900 and all but the outer 2,147 feet of the east jetty in July, 1904, the least depth of the channel which was developed by tidal scour alone had not increased in 1905 beyond the 4 feet reported in 1904. It was believed that the opening through Maulover Bank afforded an outlet for a large portion of the water which would otherwise have flowed through the jetty channel, and thus was at least partly responsible for lack of scouring in that channel. It was also believed that the partial blocking of the entrance to the harbor by jetties contributed in no small degree to keeping the Maulover branch silted. It was therefore recommended that a channel be dredged between the jetties at that time, partly with the view of increasing that waterway and thereby assisting in the clearing of the Maulover branch. Accordingly, from June to December, 1905, a channel 200 feet by 12 feet was dredged through the bar between the 10-foot contours by removing 134,063 cubic

yards of sand at 23.9 cents per cubic yard. Whether or not this dredging was a contributing factor, the Canlewer passage is reported to have shoaled in 1906 and finally closed in the spring of 1909 (1909 Report of Chief of Engineers, page 30).

12. A survey of the jetty channel made in June, 1909, showed that considerable scour had taken place throughout most of the dredged channel, but that a bar about 400 feet wide had formed just outside of the end of the east jetty over which there was a minimum depth of 10.7 feet. The United States Dredge Company removed 32,374 cubic yards of sand on the outside of the outer bar at a cost of \$9,732.41 in September to November, 1909, inclusive, but did not restore the 12-foot channel. This constituted the first maintenance dredging. Another survey in June, 1910, showed minimum depth of 10.3 feet in the channel over the outer bar.

13. A contract partly for maintenance and partly to increase the central 130-foot width of the channel to a depth of 17 feet was commenced May 8, 1911, and completed August 16, 1911, at a price of 19.9 cents per cubic yard, new measurement. A total of 207,004 cubic yards of sand were removed. An additional contract was entered into for dredging a depth of 15 feet at mean low water on either side of the 17-foot channel just dredged, price, 22.7 cents per cubic yards, new measurement. From August 21 to September 27, 1911, 12,533 cubic yards were removed on this contract. Of the costs on these two contracts, about \$12,000 was charged to new work and \$62,000 to maintenance. On June 30, 1912, it was reported that

the shallowest part of the locality under improvement was 12.3 feet, although there was an available channel of 15-foot depth, with a minimum width of 100 feet.

11. Further dredging operations were commenced until April 21, 1914, when a contract was begun under which it was intended to enlarge the jetty channel to about 150-foot width and 15-foot depth at a price of 15c.0 cents per cubic yard. This contract was completed on September 5, 1914. About \$10,000 was charged to new work and \$11,000 to maintenance. The channel between the jetties was widened about 50 feet for its full length, 1.4 miles, and some shoals which had formed in the previously dredged area were removed, making the width of channel about 300 feet and the depth 15 feet at mean low water. An additional width of 150 feet and same length was partially dredged, over the greater part of which there was a depth of 12 feet. A total of 200,174 cubic yards was removed under the contract.

12. Maintenance dredging. - As previously described, the dredging between the jetties in 1905 revised the original 100-foot by 12-foot channel. The 1909 dredging on the outside of the outer bar was for maintenance but did not restore the 12-foot channel. In 1911 a central depth of 17 feet and side depths of 15 feet were revised, and in 1914 the channel was brought practically to its present dimensions (300 feet by 15 feet and an additional width of 150 feet to 12-foot depth). A summary of maintenance dredging to 1914, described previously, and subsequent maintenance

dredging is given in the following table. Changes in offshore contours have been added to drawing R. & H. No. 256. Airplane oblique views of Hantucket Harbor are included as Plates 1 and 2.

Perio	Volume Cubic Yards	Unit Price	Total Cost Including Government Costs	Source
Sept. to Nov. 1929	32,574	-	3,732.41	J. S. DREDGING
May to Sept. 1931	251,000 (1)	(19.94) (22.74)	62,000.00 (1)	Contract
April to Sept. 1934	42,000 (2)	15.98	11,008.00 (2)	Contract
July 1934 to April 1925	22,329	53	13,061.53	Contract
June to Sept. 1929	36,333 (3)	31.8	32,333.95 (3)	Contract
June to August 1936	131,660	-	32,706.18	J. S. DREDGING
Total	506,696		1154,500(approx.) (4)	

- (1) About 43,500 cubic yards additional, cost about 412,000 charged to new work.
- (2) About 226,000 cubic yards additional, cost about 240,000 charged to new work.
- (3) Under the same contract 79,229 cubic yards additional were removed in widening the turn outside of Brent Point by 350 feet and charged to new work, total cost, 129,386.55.
- (4) Including cost of intervening surveys, etc.

16. All spoil from dredging was deposited in deep water in Hantucket Sound, except that from the 1934 - 25 contract. The disposal area for that dredging was between the jetties, north of Brent Point and west of a line parallel to and 500 feet west of the westerly channel line, as shown on drawing R. & H. No. 256.

17. Of the maintenance dredging, all that in 1924 - 25 was at the inner bar; in 1929 and 1936 it was partly on the inner and outer bars.

The total volume removed from the inner bar was about 143,000 cubic yards with a total cost of about \$42,000, while the total from the outer bar was 98,000 cubic yards costing about \$27,000.

18. An examination made in March, 1936, prior to dredging showed a minimum width of about 350 feet between 12-foot contours at the inner end of the dredged channel. Most of the 1936 dredging at this location was not in the channel proper, but was on the area at the turn that had been widened in 1929. Several feet overdepth were secured in this area in 1936. In the west edge of the 300-foot channel a cut about 2,000 feet long and 50 feet wide was dredged in 1936. The depth before dredging this cut averaged about 14 feet and after about 17 feet. It may be said that the 300-foot by 15-foot channel was practically self-maintaining at this inner bar. A large proportion of the work there in 1936 must be considered as advance maintenance. Between the inner and outer bars no dredging was done in 1936. Depths in the central 200 to 250 feet generally exceeded 18 feet and the distance between 16-foot contours averaged over 300 feet. Between the outer ends of the jetties the western side of the 300-foot channel had shoaled slightly. Depths along the western edge averaged about 13 feet. Beyond the end of the east jetty the 15-foot contour extended over the western half of the channel for a length of about 1400 feet, but the average sounding in this area was about 14.5 feet. The shoaled area beyond the end of the west jetty was dredged to an average depth of 17 or 18 feet in 1936. It is believed that not more than about

one-quarter, or about \$6,000 of the 1936 dredging should be charged to the maintenance for the 1934 - 1936 period. The total cost of maintenance dredging over this period would therefore be about \$52,000, about \$30,000 on the inner and \$22,000 on the outer bar. The average annual cost would be about \$1,360 on the inner and \$1,000 on the outer bar. The average interval between dredging has been about seven years. The jetties have maintained better than a 15-foot by 300-foot channel, except for a short inner bar, and the outer bar beyond the ends of the jetties.

19. Jetty Maintenance. - The west jetty was completed approximately to its present length in 1900 and the east jetty in 1907. Previous to these dates some additional stone had been added to settled portions of the completed jetties and charged as maintenance. The section adopted for the east jetty in 1905 was 4 feet wide on top, the same as the outer end of the west jetty. Possibly due to washing down by wave action, the section shown on a drawing dated 1922 is 6 feet wide on top. Subsequent repairs were made to this dimension. The following summary gives the total costs of jetty maintenance including government costs.

<u>West Jetty</u>		<u>East Jetty</u>	
<u>Fiscal Year</u>	<u>Cost</u>	<u>Fiscal Year</u>	<u>Cost</u>
1934	\$7,210	1930	\$ 5,000.
		1937	1,312.50
		1937	5,310.36
		1936	11,570.76
		1936	55,510.24
		1937	1,150.24
Total	<u>\$7,210</u>	Total	<u>\$209,700 (approx.)</u>

It appears more logical to charge stone added to settled portions before completion of the jetties to new work. On this basis, annual maintenance costs on the west jetty would be zero, and on the east jetty about \$3,450 or 70.50 per linear foot. These figures are slightly less than previously reported.

30. Conclusions. - The original purpose of these jetties was to obtain a 12 to 14-foot channel by tidal scour without dredging. They failed to accomplish this result. Their effect on the controlling depth before dredging was an increase of only 2 feet from 6 feet to 8 feet. The concentration of the tidal currents was apparently insufficient to produce the necessary scouring action. Parallel jetties with closer spacing and extension of the west jetty to project length (about 300 feet further than at present) may have assured the desired channel by tidal scour. With parallel and closer jetties the volume of the tidal prism should be sufficient to maintain the project channel even though the original dredging was found to be necessary. The costs under the existing project to June 30, 1937, have been \$56,442.25 for new work (divided approximately west jetty, \$135,000, east jetty, \$109,000, dredging, \$132,000), and \$271,448.53 for maintenance (divided approximately west jetty, \$7,210, east jetty, \$109,000, dredging, \$154,500), a total of \$728,130.78. This total expended on parallel and longer jetties with possibly initial channel dredging would probably have assured a self-maintaining channel. At 3-1/2 per

cent interest and including jetty maintenance, the annual carrying charges would be about \$30,000. In comparison, the interest charges at 3-1/2 per cent on the cost of the present installation (about \$470,000 including jetty maintenance prior to completion), and average annual cost of maintenance since completion (about \$5,000) total about \$22,500. The probable dredging costs for maintaining the present channel without jetties can only be based on the experience gained in 1929 - 32, when a 17-foot channel is said to have nearly filled in one storm. To secure the present channel dimensions by dredging through the original bar would have required the removal of about 700,000 cubic yards. At an average unit cost of 20 cents, and with interest at 3-1/2 per cent, the annual charges on the original dredging would be about \$5,000. To be more economical than the present installation, annual maintenance would have to be less than about \$17,000. At the same unit price this would remove 35,000 cubic yards. Whether this volume of dredging would suffice to maintain the desired channel must remain a matter of conjecture. It should be noted that the currents striking Grant Point have secured a channel of considerably greater dimensions than the project channel. This fact leads to the question of whether it would have been possible to maintain this same concentration of currents along a curved west jetty, and thus succeed not only in scouring the original channel, but in making it entirely self-maintaining, at least to the end of the jetty. Beyond that, an outer bar

would probably form, but its maintenance would probably be cheaper by dredging than by extending the jetty into deep water. Such a jetty would have been built at somewhat greater cost in deeper water than the present west jetty, at least near its inner end, but should have eliminated the inner bar in its present location. A relatively short east jetty may have sufficed to protect the channel from the southwestward littoral drift along Coatsville Beach. It is estimated that such a project could have been built including original dredging, if required, for about one-half the cost of the present installation, and its annual charges including maintenance dredging, of the outer bar would probably not exceed \$10,000 to \$12,000.

The value of the jetties as breakwaters is well established by the just requests of local interests to raise them in order to secure greater protection from northeastern storms for shipping and shore structures in the harbor, especially north of Grant Point. In 1936, additions to the jetties were partly to give this increased breakwater protection.

Block Island Harbor of Refuge, Rhode Island

1. Conditions prior to construction. - The location of the Harbor of Refuge is on the open ocean. There was no tidal basin, and consequently no tidal rise prior to construction. The mean range of tide was about 3 feet.

2. Construction. - The original project was based upon a report of a board of engineers printed in Senate Miscellaneous Document No. 31, 40th Congress, 2d Session, and consisted of a breakwater extending from the shore northerly for 600 feet, the estimated cost being \$72,000. The first appropriation was \$30,000 in 1870. The expensive too-wall and stone facing of the original project were dispensed with and riprap was used. The project was modified several times as outlined in Annual Report of Chief of Engineers for 1913, page 134. The present dimensions of the structures are shown on the print previously submitted, W. A. D. C. 153. This drawing has been revised to show changes in offshore contours. An airplane oblique view of Block Island Harbor of Refuge is included as plate 3. The existing project is described in Annual Report of Chief of Engineers for 1937, page 100. Despite numerous attempts to tighten the east breakwater and prevent passage of sand into the harbor, considerable shoaling still occurs, and maintenance dredging is usually required about every three years.

3. Dredging. - The small basin in the inner harbor was originally built to shelter plant engaged on the breakwater construction. This basin was dredged to a depth of 7 feet at mean low water in 1873 and to

9 feet in 1880. The latter dredging consisted of removing 16,116 cubic yards at a contract price of 25 cents per cubic yard. The first maintenance dredging was by the U. S. Dredge RHODE ISLAND in November and December, 1889, when 3025 cubic yards of sand were removed from a bar along the western side of the east breakwater, making a depth of 9 feet at mean low water. During July and August, 1893, Government plant removed 4,452 cubic yards of hard sand to a depth of 12 feet at low water from the shoaled entrance to the enlarged inner harbor and 160 cubic yards of soft mud to a depth of 10 feet from the shoaled entrance to the inner basin. In June and July, 1895, 3,123 cubic yards of mud and gravel were removed from the shoaled entrance to the harbor near the end of the west breakwater, and 310 cubic yards of mud and sand from the shoaled southwest corner of the inner basin to a depth of 9 feet at a contract price of 33-1/3 cents per cubic yard measured in scows. The entrance to the inner harbor had shoaled again by the spring of 1896, and 2,704 cubic yards were removed at 30 cents per cubic yard in June, 1896, leaving a minimum depth of 10 feet. The shoal had formed again by the spring of 1897. In June and July, 1897, 5,000 cubic yards of sand were removed at a contract price of 35 cents to a depth of 10 feet at low tide. The entrance was again dredged to 10 feet in June, 1898, by removing 5,500 cubic yards at 32 cents, and in June, 1902, when 9068 cubic yards were removed at 24 cents. In August and September, 1902, 11,640 cubic yards were removed at 23 cents and in June, 1903, 2,954 cubic yards at 50 cents.

4. Under the 1906 revision of the project, part of the inner harbor was dredged to 10 feet in September to December, 1905, and March to June, 1906, when 89,354 cubic yards of sand, clay and small boulders were removed at 21 cents per cubic yard. This work was resumed in July, 1907, and completed in September, 1907, under a contract by which 32,226 cubic yards of sand and clay were dredged at 30 cents per cubic yard. Excavations to the east breakwater in 1906, sand continued to seep through and shoal the harbor. The shoaled area was maintained to 10 feet by the removal of 16,300 cubic yards of sand at 21-1/4 cents in August to October, 1909.

5. A project adopted in 1912 provided for a depth of 15 feet in the inner basin and in the inner and outer harbors and for the present dimensions of the dredged areas. From September to November, 1913, 113,347 cubic yards of sand, mud, and clay were removed at 28.9 cents in dredging the 15-foot by 100-foot entrance channel. Due to a severe storm on March 1, 1914, emergency maintenance dredging was required, under which 62,405 cubic yards at 28.9 cents were removed in June to August, 1914. Further new dredging on the existing project in July to November, 1915, consisted of removing 136,537 cubic yards at 19-3/4 cents, and 19,670 cubic yards at half-price between the depths of 15 and 17 feet at mean low water from the inner harbor. The controlling depth was reported as 14 feet as determined in 1916. A channel 15 feet deep and 100 to 150 feet wide was dredged

as maintenance by the U. S. ARMY CORP during March and April 1921. The volume removed was 10,925 cubic yards. The expenditures were \$4,733.64.

6. Shoaling due to travel of sand through or over the east breakwater during heavy easterly storms continued and subsequent maintenance is shown in the following table, which summarizes all the dredging.

New York or Maintenance	Date	Volume 150 cu. yds. (cubic yards)	Unit Price \$ per cu. yd.	Location
New York	1873	1	—	Small basin in inner harbor
New York	1880	10,166	28	Small basin in inner harbor
Maintenance Nov.-Dec. 1889		5,025	Govt. Plant	Outer along west side of east breakwater
Maintenance and July-Aug. 1893		4,400	—	Entrance to enlarged inner harbor
New York		260	—	Entrance to inner basin
Maintenance June-July 1895		5,125	25-1/3	Entrance near end of west breakwater
		318	25-1/3	Southwest corner of inner basin
Maintenance June 1896		2,700	30	Entrance to inner harbor
Maintenance June-July 1897		2,000	25	Entrance to inner harbor
Maintenance June 1900		5,000	28	Entrance to inner harbor
Maintenance June 1902		5,000	24	Entrance to inner harbor
Maintenance Aug.-Sept. 1902		11,625	25	Entrance to inner harbor
Maintenance June 1903		2,200	20	Entrance to inner harbor
New York Sept.-Oct. 1905		32,325	24	Part of inner harbor
	March-June 1906	32,325	24	Part of inner harbor
New York July-Sept. 1907		2,225	28	Part of inner harbor
Maintenance Nov.-Dec. 1909		10,000	25-1/4	Part of inner harbor
New York Sept.-Dec. 1910		31,240	24-9	Entrance channel
Maintenance June-August 1911		42,300	24-9	Entrance channel and harbor
New York		100,300	25-2/4	
	July-Dec. 1915	13,670	27-1/8	Inner harbor
Maintenance March-April 1921		10,925	Govt. Plant	Inner channel
		154	—	

*Half price between the depths of 15 and 17 feet.

New York or Maintenance	Date	Volume : Unit : Tides (Cu. Yds.: (cubic))	Unit	Location
Maintenance May-June 1922		7,778	63-1/2	Channel
Maintenance May-June 1925		13,758	59	Channel
Maintenance June-July 1930		26,603	42	Channel
Maintenance July-August 1930	22,197	47		Channel
Maintenance June-July 1932		17,836	36	Channel
Maintenance May-July 1934		15,795	30-1/2	Channel
Maintenance October 1934		1,964	37.97	Corners of basin
Maintenance June-July 1937		13,474	41-9	Channel

It is believed that all soil was dumped in deep water at sufficient distances so as not to affect conditions around the breakwaters, except in 1930 and 1937. In these years soil was deposited on a marsh behind the high-water line by pipe line.

7. Volume of Tidal Prism. - The areas of the inner harbor and basin combine about 300,000 square feet. With a mean range of tide of about 3 feet, the tidal prism is thus approximately 2,400,000 cubic feet inflow and outflow per tidal cycle. The cross-section area of the gorge between the east breakwater and the end of the west breakwater was about 2,300 square feet at half tide level in April 1937, before dredging, and in July, 1937, after dredging, about 3,000 square feet.

Block Island, Rhode Island - Great Salt Pond

1. Conditions prior to construction. - A harbor or refuge at Block Island has been the subject of reports since 1867. At that time Block Island had no natural harbor. The cutting of a channel through the barrier into Great Salt Pond was considered as an alternate at that time, but was discarded in favor of the construction of an artificial harbor on the east side of the island, by enclosing an area with breakwaters. For sanitary reasons, and to prevent overflow of surrounding lands, local inhabitants opened several small ditches into Great Salt Pond, but the sand movement along the west coast of the island gradually closed these openings. An outlet, reported to have been made in 1807 at a cost of nearly \$10,000, was about 50 feet wide and 4 feet deep, and was reported to be still open in 1873. A map dated October, 1892, shows a cut 3 feet at mean low water and about 50 feet wide, which is said to have been made in April, 1892. Probably both references are to the same cut. The map indicates a tidal range of 0.5 feet inside the pond near the cut. From this range and the area of the pond, about 30,000,000 square feet, it may be computed that the volume of the tidal rise through the cut was ten to fifteen million cubic feet. The mean tidal range in the Sound outside the pond was given as 2.8 feet in 1895. It is given as 2.6 feet by the 1939 Coast and Geodetic Survey Tide Tables.

2. Construction by local interests. - In 1895 and 1896, the State of Rhode Island and the Town of New Shoreham dredged a channel 300 feet

wide and about 12 feet deep between the pond and the ocean, and built the south jetty to a length of 857 feet and the north jetty about 250 feet in length. The distance between jetties was about 750 feet. In 1897 it is reported that with funds appropriated by State and Town, totaling \$115,000, in addition to the jetty construction a channel had been dredged 450 feet wide with a minimum width of 150 feet carrying 12 feet at mean low water. The south jetty was made sand-tight with a 3-inch tongue and groove oak plank sheathing driven 3 feet into the bottom along its axis. A core of chipstone was also incorporated into the granite rubble construction. Details are described on pages 420-1 of Annual Report of Chief of Engineers for 1896. Contract prices were 10.7 cents per cubic yard for dredging and 1.33 per ton for the jetty stone.

5. Federal project. - The existing project, adopted in 1896, was based on a report printed as Document No. 97, 54th Congress, 1st Session. It provides for a channel 450 feet wide with a central depth of 25 feet for a width of 150 feet, sloping gradually up to a depth of 12 feet in a width of 500 feet and thence up to low water level with a bottom slope of 1 on 4 for two riprap jetties, the southerly one to extend to the 12-foot contour, with a top width of 15 feet at an elevation of 8 feet above mean low water and side slopes of 1 on 1 on the channel side and 1 on 2 on the south side, the northerly one of indefinite length estimated to cost \$20,000 to act as a breakwater. The sheathing as used in the state jetty was to be omitted, but a core of small rubble was provided. The Federal north jetty has not been constructed. An airplane oblique view of Great Salt Pond, Block Island, is included as Plate 4.

4. Construction of the Federal portion of the south jetty was in progress, October - December, 1896, and April - July, 1897. A total of 26,321 tons of stone were placed under contract at \$1.33 per ton, extending the jetty to the 12-foot contour, 1,262 feet from shore. A channel examination made in August, 1897, revealed that the gorge had scoured to a maximum depth of almost 31 feet. The controlling depth outside the gorge and north of the south jetty was slightly over 12 feet. There was apparently a small amount of shoaling as in August and September, 1898. 10,756 cubic yards of material were removed at \$1.75 cents per cubic yard to secure a channel of 12-foot depth. The exact location of this work is not readily available.

5. A severe storm on March 2 - 3, 1900, damaged the outer end of the south jetty by undermining, "the cut being from 7 to 8 feet in water that was 18 to 20 feet deep when the head of the jetty was completed, while in advance of the jetty the shoaling amounted to from 6 to 8 feet and extended out a distance of 250 feet. There was some shoaling in the channel, but in less degree." (Annual Report of Chief of Engineers for 1900, Appendix D, page 1277.) In June, 1900, it was stated that the low water shoreline on the south side of the south jetty had advanced 130 feet since April, 1899, and the sand had been raised back of it so that it was even with the top of the jetty and was being carried into the channel when the wind was from south around to west.

6. The project was modified in June, 1900, to extend the south jetty 350 feet, and to locate a north jetty 600 feet from it (not a continuation of the State jetty) and about 1,300 feet long.

7. Jetty extension and maintenance. - Due to damages to the jetty by the March, 1900, storm, repairs were made in June and July, 1900, by contract under which 1,613 tons of stone were placed at \$1.40 per ton. Further repairs by contract were made in August, 1901, when 3,958 tons of stone were placed at \$1.23 per ton.

8. The extension of the south jetty was begun in April, 1903. The contract was completed in September, 1903, the jetty having been extended 287 feet, by the placing of 23,989 tons of stone at \$1.23 per ton. The total length at this date was 1,549 feet from the initial point on shore. In September to November, 1905, the south jetty was completed to its present length of 1,691 feet, by an addition of 142 feet, by contract under which 12,013 tons of stone were placed at \$1.23 per ton.

9. In August, 1935, under contract, 1,436.3 long tons of riprap were placed in repairs to the south jetty. The costs for this work were \$9,655.12. This work constituted the only repairs to the jetty since its completion in 1905. The annual maintenance cost since completion averaged about \$100, or about 11 cents per linear foot. With repairs made in 1900 and 1901, the expenditures for jetty maintenance total about \$13,000.

10. Subsequent dredging. - A contract for dredging a channel 300 feet wide and 16 feet deep at mean low water was commenced in December, 1909, and completed September, 1910. Under it 132,210 cubic yards of sand, clay and cobblestones were removed at 11-1/2 cents per cubic yard

and 145 cubic yards of boulders. Work on a contract to deepen the central portion of the 16-foot channel to 25 feet was in progress September to December, 1900, by which 43,736 cubic yards of sand, clay and cobblestones were removed at 29-1/4 cents, completing one cut of about 30 feet in width and 25 feet in depth through the center of the channel. 45 cubic yards of large boulders were also removed in these dredging operations.

11. The 1903 Annual Report of Chief of Engineers, Appendix I, page 103, reports dredging of the channel as follows: "The channel dredged in 1900 to a depth of 18 feet, with a width of 300 feet, with a 25-foot deep cut through the center, has scoured to some extent. The sides of this channel now have about 15 feet of water, from which it deepens to 18 feet toward the center. The 25-foot cut has scoured to 19 feet near the outer end."

12. A contract for dredging the shoal at the sea end of the entrance was begun in June, 1903. By September, 1903, 4,610 cubic yards had been removed at 26.7 cents and the work was suspended.

13. The dredging of the 25-foot depth in the entrance channel was resumed in August and September, 1905, suspended until June, 1906, and the contract completed in November, 1906. The 25-foot depth was secured for a width of 30 feet by the removal of 79,303 cubic yards of sand, clay and small boulders at 27 cents and 47 cubic yards of large boulders at \$10 per cubic yard. In June, 1907, it was reported that this channel had maintained itself.

14. The completion of the 25-foot channel 150 feet wide was secured under contract in progress September to November, 1907, and April to June, 1908. Under the contract 37,640 cubic yards of sand and clay were removed at 20-1/2 cents per cubic yard and 199.4 cubic yards of large boulders. In the 150-foot wide channel the depth secured averaged between 25 and 37 feet. The channel has never been completed to full project width. In 1909 the approximate widths through the gorge were 250 feet between the 10-foot contours, 350 to 400 feet between the 12-foot contours, and 500 to 550 feet between the mean low water lines.

15. Subsequent maintenance dredging. - A channel examination in May, 1909, showed slight shoaling opposite the end of the south jetty and along the edges. The J. J. Dredge COMPANY worked in the channel for a few days each month in June and December, 1909, removing a total of 2,467 cubic yards of sand, clay and stones.

16. In 1911 and 1912 it was reported that there was no material change in the depth of the channel. A survey in August, 1915, showed a least depth of 21 feet at mean low water in the 25-foot channel. Reports from 1915 to 1921 indicated minimum depth of 23 feet, although no dredging had been done since 1909. The survey before dredging in 1935 showed controlling depths at mean low water of about 21 feet for 150-foot width on the bar in the channel off the end of the south jetty and 10 feet or over for a width of about 200 feet throughout the channel. The central

portion of the channel had maintained depths in excess of 25 feet for an average width of about 150 feet except for a distance of about 500 feet opposite the end of the south jetty and about 300 feet at the inner end of the cut. The minimum depth at the latter location was about 23 feet.

17. From July to December, 1935, maintenance dredging restored a depth of 18 feet over a width of 300 feet. No dredging was done on the central 150 feet part of which had shoaled from 25 to 21 feet. Under the contract 51,377 cubic yards of ordinary material, 3,513 cubic yards of extra hard material, and 117.52 cubic yards of boulders were removed. The unit price was 31.5 cents per cubic yard. The costs for this dredging were \$3,443.448. Material was dumped in deep water in Block Island Sound about $\frac{1}{4}$ mile from the site of dredging.

18. Summary of dredging. - The following table summarizes the dredging at least "at cost." The quantity dredged by State and local interests is only approximate. As far as can be determined, all spoil was dumped in deep water in Block Island Sound, probably at sufficient distance so as to have no effect on conditions in the immediate vicinity of the cut. Changes in offshore contours are shown on accompanying drawing R. & H. No. 275, which is submitted to supplement R. & H. No. 259 forwarded with previous report.

Year	Volume New York or C. N. Yds. of Maintenance	Unit Contract Price
BY STATE AND LOCAL INTERESTS		
1935 - 1936	1,400,000' New York	Initial - 10.7 cents Later - 11-7/8 cents

GENERAL

Perio	Volume Cubic Yds.	New Work or Maintenance	Unit Contract Price
August - September 1908	10,756	Maintenance	14-7/8 cents
Dec. 1909 to September 1900	132,230	New Work	14-1/2 cents
September - December 1900	43,786	New Work	29-1/4 cents
June - September 1903	4,620	Maintenance	26-7 cents
August - September 1905)	19,383	New Work	27 cents
June - November 1906)	37,620	New Work	26-1/2 cents
April - June 1908)	2,467	Maintenance	H. C. BENNETT
June and December, 1909	55,370	Maintenance	31-3 cents
July - October 1909			

19. Total costs to June 30, 1908. - The total costs of this project including State and Town work have been about \$357,000 of which \$304,000 was for new work and \$53,000 for maintenance. Of the maintenance costs about \$10,000 have been on the south jetty and the remainder, about \$40,000, on dredging.

20. Tidal conditions. - The mean tidal range at Great Salt Pond is 2.6 feet. The mean range inside the Pond is not known, but it is probably little less than 2.6 feet. The area of the Pond affected by this tidal range is about 30,000,000 square feet. Assuming a mean range of 2.6 feet over this area, the mean tidal inflow and outflow per cycle is approximately 75,000,000 cubic feet. The cross-sectional area of the gorge is about 4,700 square feet at mean tide level. The width at mean tide level is about 470 feet.

31. Discussion. - The south jetty at rest salt and has not been entirely successful in maintaining a channel of the maximum dimensions dredged (25 feet deep for the central 150 feet, 13 feet minimum depth over 300 feet and about 500 feet between the mean low water lines). The project channel dimensions are greater than required by present navigation. The channel has never been dredged to project dimensions, nor has any maintenance dredging been done on the 25-foot depth in the central 150 feet since its completion in 1909.

32. An opportunity has been afforded to observe the nature of the channel that was maintained without dredging from 1909 until 1935. The following channel conditions were shown by the survey before dredging in 1935. During the period there was shoaling on the outer and inner bars and along the edges of the channel between these bars. At the latter location, a channel with depths in excess of the 25-foot project depth maintained itself for an average width of about 150 feet. In the gorge cut through the beach there were depths in excess of 25 feet over a width of about 200 feet, depths in excess of 13 feet over a width of about 150 feet, and depths in excess of 13 feet over a width of about 300 feet. The width of 300 feet had been dredged to 13 feet and over. Just outside the bar, for a distance of about 500 feet, the width between 25-foot contours averaged slightly less than 150 feet, between 13-foot contours about 200 feet, and between 10-foot contours about 225 feet. Between this

stretch and the outer bar the dredged channel very nearly maintained itself. It may be assumed that the tidal prism of about 70,000,000 cubic feet is therefore sufficient to maintain a channel through the gorge with low water depths of 15 to 20 feet for a width of 150 feet, and depths exceeding 12 feet for a width of 300 feet sloping thence to a high water width of approximately 500 feet. It seems probable that a north jetty carrying the gorge 500 feet high water width out about 500 feet would make this cross-section self-maintaining as far as the outer bar, but its construction would probably not be economically justifiable.

33. In the inner bar where the cut opened into the pond the minimum width between 25-foot contours was about 40 feet, but the lowest depth at mean low water in the central 150 feet was about 23 feet. The width between 10-foot contours at this location averaged about 300 feet and between 12-foot contours exceeded 400 feet. The cross-section as originally dredged has been practically self-maintaining except for the slight shoaling in the central section.

34. An outer bar about 500 feet wide extended across the central 150 feet of the channel opposite the end of the south jetty. The minimum low water depth in this area in 1935 was about 20 feet. Project depths existed on both sides of this central section. The maintenance of the 25-foot depth 150 feet wide over the outer bar might require dredging of about 10,000 cubic yards not oftener than every two years.

or an annual cost probably not exceeding \$2,000. The extension of the south jetty to the present location of the 25-foot contour, a distance of about 300 feet, would probably cause the 25-foot channel to be self-maintaining. The depth of water at the end of the jetty had shoaled from about 23 feet to 12 feet since its completion. This extension of the jetty with the same top width and elevation would require about 30,000 cubic yards of stone and probably cost about \$300,000. It is apparent that such an extension could not be justified.

5. Conclusion. - It has been suggested by some observers that the northern part of Block Island was once a separate island. Great Salt and was then a strait lying between the two islands. Large quantities of material eroded from the two islands built up two bars in the form of a double tombolo connecting the two islands and enclosing Great Salt Pond. The nature of the topography appears to support this theory. A large volume of littoral drift still moves northward along the west side of the island. In view of this and the difficulty encountered in keeping drainage channels open into the pond, it appears that the cost of maintaining a channel without a jetty by dredging alone would probably be high. The total cost of the south jetty (State, Town and Federal) was about \$150,000. Annual interest charges on the jetty computed at 3 1/2 per cent would total about \$5,250. If this amount were expended for dredging, probably 30,000 cubic yards could be removed annually. Whether the removal

of this amount would maintain a channel equal to that maintained by the jetty is problematical.

26. Whether the extension of the jetty beyond the 10-foot contour by 429 feet in 1903 - 05 was justified is worthy of consideration. The cost of the extension was about \$40,000. Interest on this cost at 3-1/2 per cent and maintenance at 11 cents per linear foot makes the annual costs about \$1,750. An 18-foot by 300-foot channel with a 30-foot wide center cut 25 feet deep had been secured in 1900. An examination in December, 1932, revealed that the 25-foot depth had shoaled to about 10 feet at the outer bar and the 18-foot depth had shoaled an average of about one foot. The estimated volume of shoaling was about 15,000 cubic yards, or at a rate of about 7,500 cubic yards yearly. The cost of this work at recent prices would exceed the annual charges on the jetty extension. In a location where two jetties are required, the annual charges could be doubled, and dredging of the same volume of material would probably be cheaper.

27. The average annual cost of maintenance dredging from 1906 to 1935 has been about \$700. This would be 3-1/2 per cent on a \$20,000 investment. probably an extension of about 150 feet could have been made with this sum at the rates obtained in 1905 and 1906. Whether the further extension by this distance would have completely eliminated maintenance dredging is doubtful.

12. Experience at Great Salt Pond indicates that the construction of a jetty of moderate length supplemented by some maintenance dredging probably resulted in the lowest annual charges. While extending the jetty into deeper water may have given greater depths over the outer bar, the cost per linear foot of jetty increases so rapidly with depth of water, that the savings in maintenance would have been overbalanced by the annual charges on the jetty extension. This would be especially true where frequent changes in the direction of the littoral drift make two jetties necessary. This jetty is considered an example of an efficient and economical jetty construction for the depth required.

Connecticut River, Connecticut

Jetties at Saybrook Outer Bar

1. Conditions prior to construction. - The Annual Report of the Chief of Engineers for 1873, Appendix I, pages 43 to 67, inclusive, contains a description of conditions prior to 1872. The theory upon which the design of the jetty system was based is fully explained on page 61 of that report. The report upon which the initial project was based is also printed as Executive Document No. 123, 42d Congress, 3d Session. Further details on the early work are given on pages 603 and 564, Appendix G of the Annual Report of Chief of Engineers for 1889. In 1836 \$20,000 was appropriated for removing the bar. Survey report on the project printed in House Executive Document No. 252, 25th Congress, is not on hand in this office. Project was approved to dredge a cut 500 feet wide and 12 feet deep at mean low water in the west channel, at an estimated cost of \$4,500.50 based on a price of 15 cents per cubic yard. The volume involved must therefore have been about 300,000 cubic yards. The available depth over the bar is said to have been 7 feet before dredging. Work was begun in May, 1833, and continued until the fall of 1840, when the appropriation was exhausted, 26,354 cubic yards of sand and stones having been removed, making a channel 1,500 feet long, 50 feet wide and from 11 to 12 feet deep. This channel was nearly destroyed by storms and freshets in the following

winter and spring. In 1943, \$3,471.57 was appropriated to pay a balance due the contractors. The total cost of this ineffectual dredging must therefore have been \$3,471.57.

4. Ideal conditions. - The mean tidal range is given as 3.49 feet at Dogbrook Bar and 3.20 feet at Saybrook Point, about one mile up the river, as determined in 1972. The 1959 Coast and Geodetic Survey Tide Tables give a range of 3.6 feet at the jetties. No determination of the tidal range is available, either before or after construction. A rough approximation may be computed from the velocity given in the Coast and Geodetic Survey Current Tables and the cross-sectional area of the river. The mean flood and ebb velocity at strength of current in the channel east of Lynde Point is given as 0.3 knot. It will be assumed that the duration of the flood and ebb are equal, that the mean velocity throughout the cross-section is 70 per cent of the channel velocity, and that the mean velocity for the flood or ebb period is 60 per cent of the velocity at strength of the current. The latter assumption is based upon the fact that the current curve approximates a sine curve. The cross-section area of the river from the light on Lynde Point to Griswold Point is about 57,400 square feet at mean low water, 46,100 square feet at half-tide level, and 35,100 square feet at mean high water. On the basis of the foregoing assumptions the average of the inflow and outflow would be

620,000,000 cubic feet. The mean fresh water discharge at the mouth is about 10,000 cubic feet per second, equal to about 430,000,000 cubic feet each during the flood and ebb currents. The mean inflow would therefore be about 300,000,000 cubic feet, and the outflow about 1,050,000,000 cubic feet. Necessarily these figures are only the roughest approximations.

The volume of the tidal prism passing between the jetties is much smaller than these figures. The half-tide level cross section between the jetties is about 7,500 square feet, or only 30 per cent of the total cross-section area of the river at its mouth. The inflow between the jetties is therefore in the neighbourhood of 10,000,000 cubic feet, and the outflow about 270,000,000 cubic feet.

5. Jetty construction. - The original report upon which the Baybrook jetties are based recommended pile and timber crib jetties 20 feet wide filled with stone. The design was changed before the beginning of construction in June, 1873. The section used was triangular with side slopes of 1:3 with the apex up to the level of the highest water, and consisted entirely of riprap stone. By June, 1874, 1,600 feet of the west jetty had been completed, using 17,500 tons of stone at a contract price of 12.25 per ton. In September, 1874, work on the west jetty was resumed. The jetty was extended to a total length of 2432.5 feet by the addition of 7,000 tons at 11.95 per ton. The total cost of the west jetty as completed at this time was about \$58,000.

The east jetty was begun at its north end in June, 1875, and 347 feet were completed in that month. This contract was completed in October, 1875, by placing 3,173 tons of stone at \$1.59, thereby extending the jetty 1,161 feet from its initial point. A contract for furnishing and placing river granite at \$0.77 per long ton was in progress in September, 1875, and from May, 1879, to January, 1880. A total of 3,155.9 tons were placed on the east jetty. By June, 1879, the east jetty had been extended about 220 feet to a total length of 1,372 feet. An additional 765 feet were completed by January, 1880, bringing the end 2,137 feet from the initial point.

The extension of the east jetty was continued from September, 1880, to January, 1881, under contract at \$1.05 per long ton. A total of 3,124 tons were placed, principally on the east jetty building it up where it was too low and extending it 161 feet to the 12-foot contour. A small amount of stone was placed on low parts of the west jetty.

From July to November, 1881, 4,304 tons of stone were placed at \$1.27 per long ton, principally in raising low places in the jetties where settlement had occurred. The amount used on each jetty is not given.

From about November, 1884, to September, 1885, 10,322 tons of stone were placed at \$1.16 per ton in an extension of the west jetty to the 16-foot curve. The length completed by this work is variously reported as 320 and 360 feet.

When the jetties were begun in 1873, the height of the jetties was intended to be the level of the highest tide, about 5 feet above mean low water. Both jetties had been strengthened in the ensuing years. From November, 1886, to June, 1887, the east jetty was built up about 3 feet over its entire length, using 6,239 tons of stone at \$1.14 per ton and bringing it above high water level. From June to August, 1887, 1,020 tons of stone was placed on the west jetty under the same contract. Probably all this work was charged to maintenance.

In December, 1887, a new project was adopted by which the jetties were to be raised to a height of 5 feet above high water with a top width of 6 feet.

The west jetty was repaired and enlarged from April to June, 1888, during which time 12,715 long tons of granite were placed at \$1.02 on the portion from the bend to the outer end, bringing this part to project dimensions, 4.1 feet in height above mean low water, 6 feet top width, and side slopes of 1 on 1. The division of this work between new work and maintenance is not given.

Jetty maintenance. - During October, November, and December, 1876, 1,440 tons of stone were used in repairing the west jetty at places where the stone had settled. During the fiscal Year 1880 it was reported that some stone was used in bringing up low places in the west jetty to the

required level, but no quantity or cost was given. Between September, 1890, and January, 1891, a small amount of stone was placed on the west jetty.

From July to November, 1891, 4,92 $\frac{1}{4}$ tons of stone were placed at £1.20 per long ton, principally in raising low places in the jetties where settlement had occurred. The quantity used on each jetty is unknown.

A small gap in the west jetty was closed by the use of 40 tons of stone at £1.16 in 1895.

Repairs to the jetties were begun in November, 1904, suspended for about three months and completed in June, 1905. 4,20 $\frac{1}{4}$ tons of stone were placed on the west jetty and 3,36 $\frac{1}{4}$ tons on the eastern one at a contract price of £1.23 per ton. The jetties were restored to a height of 10 feet above low water and 6 feet width on top. The jetties had never been built to the full height adopted in 1897.

In 1914 the west jetty was repaired and enlarged in section as previously described. From June to September, 1914, the area abeamward of the bank was repaired. The quantities entering into this work comprised 35 cubic yards of concrete capping blocks and 1,036 long tons of riprap. Much remodelling of the stones already in place was necessary. The total cost of this work was £4,732.25.

Light repairs were made to the inshore end of the west jetty during Fiscal Year 1926, using 3.5 long tons of riprap at a total cost of £1,124.25.

Repairs were made to both jetties from July to October, 1935, by contract under which 5,775 long tons were placed on the east jetty and 1,176 tons on the west jetty, a total of 6,951 tons. The costs were \$21,472.53. These repairs were to restore the jetties to their former heights and a top width of 6 feet. The top of the east breakwater is at an elevation of 5 feet above mean low water. It has never been built to the height of 5 feet above high water adopted in 1887.

The west jetty was severely damaged by the September 21, 1938, hurricane. Repairs are contemplated in 1939. It is estimated that about 2,100 long tons of stone will be required.

It is a matter of opinion which jetty costs should be charged to new work and which to maintenance. The west jetty was completed to original project cross section in 1875 and the outer end in 1885, and to the 1887 project cross section in 1914. Repairs to this jetty since its enlargement were made in 1916 and 1935 at a cost of about \$5,000, or an average annual cost of about \$250, or 9 cents per linear foot. The east jetty was completed to original project cross section in 1891. It was strengthened in ensuing years bringing its top width to 6 feet, but not to the 1887 project height. probably 1887 marked its completion to the present section. Repairs since that date were in 1905 and 1935 amounting to about \$23,000, averaging \$500 annually or 32 cents per linear foot.

5. Dredging. - The project adopted in 1873 contemplated dredging a channel to a depth of 9 feet at mean low water and 400 feet wide. It was believed that the contraction afforded by the jetties would make the channel self-maintaining, but would not occur the desired depth within a reasonable time. Accordingly, the first dredging under this project was done in the spring of 1875, where a shoal giving less than 6 feet of depth had formed near the end of the jetty. The dredge worked four days at \$10 per day and removed 551 cubic yards. The channel was cut 9 feet deep and about .5 to 1.5 feet wide. An examination made in May, 1875, about the time of the completion of the west jetty, indicated that depths of 7 to 8 feet existed over a width of 200 to 300 feet, where the depths had been about 6 feet prior to construction. No trace of the 9-foot dredged channel can be seen on the map. Very few of the soundings exceeded 9 feet. Apparently the 9-foot channel shoaled, but there was some scouring to 7 feet under the effect of the west jetty alone.

An examination in the spring of 1876 showed little if any change in the channel depth, except that a small shoal had formed at the outer end of the east jetty.

A survey of the bar was made in April, 1879. This survey revealed that the portion of the channel opposite the outer 300 feet of the west jetty had scoured so that depths of 10 to 11 feet existed over a width of 200 to 300 feet. Across the remainder of the bar depths were 8 to 8.5 feet in the center and 7 to 8 feet along the edges of the channel.

From an examination in April, 1880, it was reported that the general depth had increased about 0.3 foot by silt or sand during the previous year.

In 1881 it was believed that the scouring effect produced by the jetties had reached its limit because of the hard material. Therefore, in September, 1881, six pits were dug between the jetties by a dipper dredge to a depth of 15 feet. The material was found to be a compact, coarse sand containing a large amount of gravel and stones from 1/2 inch to 3 inches in diameter. It was believed that a depth of 12 feet was desirable at that time and that once dredged, the bar would not be re-formed. Accordingly, between October, 1881, and June, 1885, 45,411 cubic yards of sand and gravel were removed at a contract price of 15 cents per cubic yard, giving a channel 120 feet wide and 12 feet deep between the 12-foot contours.

In 1887 it was reported that the channel between the jetties had silted about a foot at either end and had narrowed slightly.

The new project adopted in 1887 provided for widening the 12-foot channel between the jetties from 120 to 150 feet. Accordingly, 11,732 cubic yards were removed between July and October 8, 1888. The channel was widened to 150 feet by this work, the expenditure being about \$3,700.

Between May and August, 1909, 16,120 cubic yards were removed from the channel between the jetties at 107/8 cents per cubic yard as maintenance.

An examination made in August, 1906, revealed that the channel between the jetties remained 12 feet or deeper for widths in excess of 130 feet for the outer 700 feet. For the remainder of the distance the controlling depth was about 11 feet with the width between 10-foot contours averaging about 150 feet.

A channel 320 feet wide and 12 feet deep at mean low water was obtained by removing 31,310 cubic yards at a contract price of 20 cents from October 21 to December 26, 1907.

A new project adopted in 1911 provided for a channel across the bar 320 feet wide and 15 feet deep at mean low water. Work toward securing the new channel dimensions was done in October and November, 1911, during which time the channel had been extended northward with full project dimensions for 360 feet from its outer end, thence 725 feet farther with full depth and width of 100 feet, and thence 700 feet with full depth and width of 175 feet. Up to the time of suspension 37,073 cubic yards had been removed at 13.5 cents per cubic yard. Work was resumed under the same contract in July, 1912, and completed in October, 1912, during which time 131,750 cubic yards were removed, bringing the channel to full project dimensions.

6. Maintenance of 15-foot channel. - The dredging of the 15-foot by 200-foot channel was completed in 1912. Subsequent maintenance dredging was as shown in the following table which also summarizes all dredging to date. The total cost of maintenance dredging since 1912 was about \$110,000, or about \$4,500 per annum average cost. The volume removed totaled 142,505 cubic yards or an average volume of about 17,700 cubic yards per annum.

The locations of the shoals as shown by examinations before each dredging are as follows: In November, 1919, the survey revealed that practically the whole channel from opposite the Light on Lynde Point to the end of the jetties had shoaled. A channel exceeding 15 feet in depth, about 1,100 feet long and averaging about 100 feet wide was located toward the west side of the dredged area and about midway of the length of the outer arm of the west jetty. Along the east side of the dredged channel a strip from 50 to 100 feet wide had shoaled to depths less than 12 feet, while a strip 10 to 60 feet wide and 1,400 feet long had shoaled to depths of from 7 to 9 feet. The remainder of the dredged channel had shoaled to an average depth of about 14 feet. In 1927 the survey showed that the western half of the dredged channel had shoaled little. A strip about 1,000 feet in length and about 50 feet wide along the west edge east of Lynde Point had shoaled to depths of 10 to 14 feet. About 200 feet of the western half of the channel between the outer ends of the jetties had shoaled to about 14 feet. Almost the entire eastern half of the channel had shoaled. Depths along the eastern edge were from 6 to 12 feet. Conditions shown by the survey of November, 1936, were quite similar to those in 1927. Shoaling was in the same locations, but was not quite as great in depth.

7. Summary of dredging. -

Date	Value in Millions	Unit Price per Cubic Yards	Total Cost of Dredging	Comments
		(feet)		
<u>1936 - 12-Foot Project without Jetties</u>				
1936 - 1940	26.914	23,471.57	50	
<u>1973 - 12-Foot Project with Jetties</u>				
Spring 1975	551	3560	35-45 1/4 days at 390 dredge rental.	
<u>1974 - 12-Foot Project</u>				
Oct. 1974 to June 1975	15,411	15%	120	
<u>1977 - 12-Foot by 400-Foot Projects</u>				
July to November 1977	20,722	3,700	130	probably inc. ov. costs.
May to August 1977	14,120	>7/84	130	all maintenance.
ct. to as. 1977	31,010	20%	200	New work and maintenance.
<u>1971 - 15-Foot by 300-Foot Projects</u>				
ct. - Nov. 1971	37,075	13.84	175-300	" " " "
July to ct. 1972	130,950	13.84	300	" " " "
<u>Maintenance of 15-Foot by 300-Foot Project</u>				
Nov. 1970 to March 1971	32,137 about 31,000	300	U. S. ARREOUS	
June and July 1979	214,434 20-20%	300	Pipe line to marsh	
Oct. 1977 to Jan. 1978	135,300 20-20%	300	on Lynde point	

Disposal of spoil on all dredging prior to 1929 was in deep water in Long Island Sound.

4. Shoreline changes. - Changes in shorelines and offshore contours are shown on revised drawing No. 4 No. 260. An airplane photograph flown in June, 1930, also accompanies this report as Plate 5. Attention is called to the seven high water lines east of a point about 700 feet west of the inner end of the west jetty. The surveys indicated a building up from 1875 to 1930, and a considerable recession from 1930 to 1938. The accretion prior to 1930 is believed to be due to the Federal jetty, possibly all this accretion occurred before 1885 when a solid masonry pier was built about 1/2 mile west of the jetty. It has caused accretion on its west side. About 1921 there may have been some erosion east of the pier, as property owners constructed several short groins in 1920 and 1921, extending them from high water to slightly beyond low water line. A small breakwater was built southeast of the pier in 1923 or 1924 by private interests to afford a harbor for small boats. The structures appear on the airplane photograph. A section of seawall about 370 feet long was built in the rear of the groins in 1928. It is reported that the groins stopped the erosion, but were not very effective in building up the beach, while it is said that the seawall has built up a good sand beach. West of the beach near the groins, for a distance of about 1,600 feet east of the pier, is shingle; the eastern end of the beach near the jetty is fine sand.

5. Conclusions. - The total cost of the west jetty including maintenance until its completion in 1914 was about \$110,000, or about 40 per

linear foot average cost. The total cost of the east jetty including maintenance prior to 1867 was about \$40,000, or about \$17.50 per linear foot average cost. The east jetty was built in shoaler water than the west jetty, and the contract unit prices of stone were lower. Unit contract prices for stone prior to 1814 ranged from \$1.14 to \$2.23 per long ton for the west jetty, and from \$0.77 to \$1.59 on the east jetty. The total original cost of the two jetties including maintenance prior to completion was therefore about \$150,000. At 3-1/2 per cent interest and including \$750 annual jetty maintenance, and \$4,500 annual dredging, the annual costs, not including any depreciation or obsolescence, would be about 10,500. If the maintenance of this channel since 1812 had been attempted by dredging alone without jetties, this sum would probably have been sufficient to remove about 40,000 cubic yards annually. This is about 12,000 cubic yards more than the average annual volume actually dredged. Whether the removal of this quantity annually would have maintained the channel in as good a condition as that actually maintained must remain a matter of conjecture.

At Maybrook the littoral drift probably moves toward the mouth of the river from both directions. The erosion on Griswold Point indicates a westward drift on the east side of the mouth. Whether this is the source of the material which shoals the east side of the channel is

not known. The east jetty was allowed to deteriorate from 1905 to 1935. The continuous shoaling of the east side of the channel during this period indicates that shoaling would have been materially greater if the east jetty had not been provided. The annual charges on this jetty are \$1,000 for interest at 3-1/2 per cent and \$500 for repairs, a total of \$1,500, sufficient to dredge about an additional 8,000 cubic yards annually. It is believed that the east jetty resulted in savings exceeding its annual charges.

Hilford Harbor, Connecticut

I. Conditions prior to construction. - The original project at Hilford adopted in 1874 was based on report printed as Executive Document No. 107, 43d Congress, 3d Session, also printed in Annual Report of Chief of Engineers for 1873, appendix V, pages 107 - 109. The original depth on the bar immediately outside the mouth of the Wappingy River was 2 feet at mean low water, and in some places between this bar and the Town wharf, the channel was nearly bare at low tide. Reason of the glacial drift along the east shore of the outer harbor by southerly storms was the predominant cause of the bar near the mouth of the river. The mean range of tide in the outer harbor was given as 6.2 feet. This value is the average of the best figures available at that time for the mean ranges at New Haven and Bridgeport, Connecticut. The mean range given by the Coast and Geodetic Survey Tide Tables for 1879 is 6.6 feet. No figures are available on the tidal ranges in Wappingy or Indian Rivers, but as these estuaries are small in area and length, it is assumed that the ranges inside are little different than those outside. The area of the two estuaries is about 8,000,000 square feet and the tidal prism is probably about 50,-000,000 cubic feet inflow and outflow per tidal cycle. The volume of fresh water outflow is negligible. From the survey of 1872 the cross-sectional area of the gorge has been determined as about 1,700 square feet at half-tide level.

2. Construction and effect of groins. - In order to arrest the erosion of the east shore of the outer harbor, and the consequent bar formation, the initial appropriation of \$5,000 was extended for the construction from September to November, 1874, of twelve short stone groins between Velah's Point and the mouth of Indian River. Ten of these groins are shown on a map dated 1861. They are spaced from 100 to 300 feet apart and are all within about 2,000 feet of Velah's Point. Of the twelve, all but two extended from high to low water mark, a length of 100 to 130 feet. They were built to a height of 9 feet above mean low water. About 5,000 tons of the stone were procured from the neighborhood of the beach and placed by teams. The remainder, about 100 tons, was purchased and deposited at the outer ends of the groins from vessels. In the 1875 report it was stated that "a considerable accumulation of sand and gravel is found on both sides of nearly all the jetties." The 1876 report states that the groins were so effective in retaining the drifting sand and gravel that the accumulated material threatened to raise the level of the beach above that of the jetties, and it was found necessary to build the shore ends higher; this was done in August, 1875, adding a height of 3 feet at high water mark. Slight repairs were made to these groins shortly after construction. They have not been maintained since then, and have deteriorated so that their locations are now indefinite.

3. Construction of jetties. - The construction of the Long jetty on the east side, at the mouth of the river, was begun on September 1, 1875. The work was done by day labor, stone to the amount of 4,096 tons being obtained from the vicinity and placed at a total cost of about \$1.35 per ton. The jetty was completed, with the exception of about 125 feet of coping, in July, 1876, with a length of 550 feet, 6 feet width on top, 16 to 18 feet width at the base and 10-1/2 feet height above mean low water. This jetty was built on a bar that was bare at low water. Light repairs were made to this jetty during Fiscal Year 1878. An addition of 61 tons of granite was made to the coping at an expense of about \$100 during Fiscal Year 1879. In 1889, the long jetty was shortened by about 60 feet to permit the widening of the 3-foot channel.

4. From November, 1879, to January, 1880, inclusive, a riprap jetty was constructed at Burns Point, opposite to and nearly at right angles with the long jetty. It was made 250 feet in length, 7 to 8 feet high above mean low water, and contained 905 tons of stone. The object of this structure was to modify the direction of the tidal currents so as to conduct them along the excavated channel, and to prevent the erosion of the west bank immediately below Burns Point, which previously resulted in forming a deposit about midway of the outside channel. Whether the construction afforded any tidal scouring action is not stated.

5. Jetty maintenance and enlargement. - Repairs were made to the long jetty in 1970. New stone in the amount of 265 tons was delivered at a cost of \$2.50 per ton. In shortening the jetty, 395 tons of stone were removed and placed to reinforce the side slopes at a cost of \$1.65 per ton for labor. An additional 10 tons of stone, recovered from the channel, were placed on the jetty in August, 1970.

6. Further work on the long jetty was in progress June to August, 1971. The cross section of the jetty was enlarged to project dimensions by widening the base and making an outer slope of 2 on 3 and an inner slope of 1 on 1, with 200 tons of stone delivered and placed at \$2.50 per ton.

7. Damage during a storm on August 24, 1973, necessitated further repairs on the long jetty. In December, 1973, 45 tons of stone were furnished and placed at \$1.50 per ton, and 10 tons of stone which were washed off by the storm were replaced at \$1.50 per ton. No further repairs have been made. As a result of the Hurricane of September 1, 1973, repairs are now needed to the extent of approximately 225 long tons of small riprap on top and slopes. To record has been found of any repairs to the lower point jetty.

8. Digging. - The initial project channel was 100 feet wide and 4 feet deep at mean low water. During October, 1975, and March to July, 1976, a total of 24,232 cubic yards were removed at 15 cents per cubic yard, thus scouring a channel 75 feet wide and 4 feet deep from the lower curve in the outer harbor to a point about 400 feet above the long jetty.

As the dredging was done simultaneously with the jetty construction, no opportunity was afforded to observe whether the jetty would effect any natural deepening of the channel by tidal scour. In the Annual Report of 1878, it was stated that the dredged channel had retained its depth.

10. In September and October, 1876, 5,400 cubic yards of mud and sand were removed from the channel above the Long jetty, making the width from 50 to 75 feet and the depth 4 feet at mean low water, except at the mouth of Indian River, where it was made from 5 to 6 feet deep. The contract work was resumed in March, 1879, and completed in September, 1879. An additional quantity of 57,578 cubic yards of mud were removed above the long jetty and 6,754 cubic yards outside the jetty. The contract price outside the jetty was 28 cents per cubic yard and that above the jetty 10 cents per cubic yard. A channel 4 feet deep and 60 feet wide was secured above the jetty, and below the jetty, the depth was 4-1/2 feet at mean low water and widened to 100 feet from 75 feet. The length of the channel from the 4-foot contour to the long jetty was about 1,300 feet.

10. Extension of the 4-foot channel above the Town wharf and dredging between Kerwina wharf and deep water was done by contract in September, 1880, and March to June, 1881. The dredging under this contract amounted to 15,000 cubic yards of mud above Town wharf at 16-1/2 cents per cubic yard and 12,000 cubic yards of sand below Kerwina wharf at 17 cents per

cubic yard. A depth of 3 feet was cut 25 feet wide within and on the west side of the existing 4-foot channel from Marvine Wharf to the 3-foot curve, except that for about 300 feet at the mouth of the Indian River, the width was 40 to 45 feet. In 1883 it was reported that the 3-foot depth was found to be fairly permanent.

11. The project was revised in 1882 to provide a channel 4 feet deep and 100 feet wide. An additional width of 40 feet was dredged to 3 foot depth, making a total width of 65 feet, for a distance of 2,750 feet from the 3-foot contour to a point opposite Marvine Wharf, under contract in June and July 1883. 30,368 cubic yards of material, chiefly sand, were removed at 11-1/2 cents per cubic yard. At the bend in the channel near Burns Point the width was made 100 feet.

12. No further dredging was done until 1889. During the intervening period there had been some shoaling of the 4-foot channel, especially at the outer end, until the available depth at low water was less than 7 feet.

13. In May and June, 1889, 18,000 cubic yards were removed at 10 cents per cubic yard, the 4-foot channel being widened to 100 feet or over across the bar at the mouth of the river. The division of this work between new work and maintenance is not known.

14. In 1894 - 95, a large volume (stated in House Document No. 230, 56th Congress, 1st Session, as "not more than 85,000 yards") was removed

under permit by private parties for oyster culture. The cost is said to have been about \$15,000. The material was taken almost wholly from the bar channel, with the result that when completed in July, 1895, the channel is said to have been 12 feet deep at mean low water and not less than 30 feet wide. The channel between the Long jetty and Horwitz Barf was 3 feet deep and about 100 feet wide.

15. By 1899 the bar channel had shoaled somewhat, with a decided shoal of very soft material just outside the gorge between the jetties where there were depths as little as 3 feet. Above the jetties the amount of shoaling was small.

16. On June 13, 1902, Congress modified the project as recommended in the report printed in House Document No. 350, 56th Congress, 1st Session, to provide a channel 10 feet deep and 100 feet wide as far as Horwitz Barf with an anchorage of the same depth of about 6 acres area on the east side of the channel north of the Long jetty, and a channel above Horwitz Barf 30 feet wide and 6 feet deep at mean low water. In 1903 it was reported that a low water draft of 2 to 3-1/2 feet could be carried as far as Horwitz Barf.

17. Contract dredging under the modified project was begun in October, 1904, and completed in April, 1905. The 10-foot channel and about 2 acres of the anchorage were completed by the removal of 47,703 cubic

yards at 16 cents, and the 6-foot channel was completed to a point 100 feet above the Town dock by the removal of 40,692 cubic yards at 14 cents. The improvement was continued under a new contract at 13.6 cents per cubic yard, under which 55,008 cubic yards were removed from June to August, 1905. Of this quantity, 42,736 cubic yards were dredged in the development of the anchorage basin and 12,212 cubic yards were from the 6-foot channel to a point 500 feet above the Town dock. At that point ledge was encountered at a depth of 9 feet. Ledge was also found in the anchorage basin and, therefore, some anchorage area was dredged on the west side of the channel.

18. No deterioration of the channel was reported in 1907 or 1908. In 1909 an examination showed an available depth of about 9 feet near the outer end of the outer channel. Reports of various years from 1910 to 1922 indicate that maximum drafts of 8 to 10 feet could be carried over the bar and as far as Marvins Wharf. A survey made in 1921 affords an opportunity to observe the channel remaining between the jetties after a period of 16 years without dredging. Both sides of the channel had shoaled, the west side several feet, the east side only slightly, the width between 10-foot contours had narrowed to about 50 feet. Outside the jetties, the unprotected channel had deteriorated little. The outer 700 feet of the channel had shoaled to an average depth of 7 to 9.5 feet. From that point

to the end of the jetties, about 1,200 feet, the 10-foot channel had shoaled little but a shoal about 700 feet long with depths of 6 to 9 feet had shifted the 10-foot contours northward.

19. The 10-foot channel was restored to project dimensions by dredging in 1922-23. An examination in September, 1930, showed shoaling averaging less than 1/2 foot in the outer 1,000 feet of the channel, about 100 feet from the end of the jetties. The channel between the jetties was of full project dimensions. By March, 1933, a shoal about 700 feet in length had formed about midway between the outer end of the channel and the jetties. Depths in this section averaged over 9.5 feet on the west side of the channel, but on the east side depths had been reduced to about 6 feet. Offshore contours from various surveys have been added to drawing E. A. R. No. 263. An airplane oblique view of Milford Harbor is included as Plate 6.

20. Summary of dredging. -

date	work or maintenance	location	volume (Cu.Yds.)	unit price
	previous project			
Sept. 1875 to July 1876	New York	100' inside jetties	24,252	18¢
Sept. - Oct. 1878	"	Above Long Jetty	5,400	10¢
March - Sept. 1879	"	"	37,378	10¢
	"	Outside"	6,784	28¢
September 1880 and)	"	Above Town wharf	15,368	16-1/2¢
March to June 1881)	"	downstream	12,000	17¢
June - July 1883	"	"	50,360	11-1/2¢
May - June 1889	Mostly new	"	18,000	18¢
	work			
1894 - 1895	Mostly new	"	95,000	Private work
	work			

Date	New York or Maintenance	Location	Volume cu.yds.	Unit Price
<u>Existing Projects Adopted 1932</u>				
Oct. 1931 to April 1933	"	Baker Harbor Point	47,700	16/-
	Maintainance Above	"	40,692	11/-
June to Aug. 1933	"	Anchorage	42,796	13.0/-
Nov. 1932 to June 1933	New York	Above Town dock	12,212	13.0/-
	Maintainance	Outer channel	22,000	25.3/-
	"	Anchorage	7,000	25.3/-
June - July 1933	"	Above Harbor Point	33,000	25.3/-
	"	10' channel and outer	39,705	17.3/-
	"	Anchorage	"	"

- This dredging was charged to New York, although part of the area had been previously dredged to 10 feet.

The 1933 dredging was deposited by pipe line behind the shoreline northwest of Burns Point, except about 1,600 cubic yards which was deposited on the beach immediately west of Burns Point Jetty. All other spoil was dumped in deep water in Long Island Sound.

11. Conditions subsequent to construction. - Channel conditions and maintenance required after construction of the jetties have been described in the foregoing paragraphs. No additional data is available on the volume of the tidal prism or the tidal ranges. The cross-sectional area of the harbor, as determined from the 1933 survey, is about 2,500 square feet at half-tide level.

12. Conclusions. - The jetties along the east side of the outer harbor temporarily checked erosion of that shore and decreased the amount of sand in motion across the mouth of the rivers. The jetties at the mouth of the

rivers have undoubtedly aided in maintaining a 10-foot channel at that location. The amount of dredging necessary to maintain the same channel without jetties cannot be estimated. It is believed that the annual cost of dredging would probably exceed the annual charges on this small jetty installation. It is evident that the jetties do not extend seaward far enough to have much effect on the channel cut to deep water. Almost 2,000 feet of 10-foot dredged channel is unprotected by jetties. However, shoaling of the portion of the channel beyond the jetties is not serious. This is probably due to the protection afforded by Pelah's Point. The average annual cost of maintenance dredging on the 10-foot by 100-foot channel outside the jetties over the period from 1905 to date has been about \$300. Obviously the annual charges on even one jetty extended to the 10-foot contour at a cost of probably \$50,000 would exceed the costs for dredging.

Naugatuck River, Connecticut

1. Conditions prior to construction. - A survey was made of the bar at the mouth of the Naugatuck River in 1872. A description of conditions at that time is printed on pages 80 to 83, Appendix A of the Annual Report of the Chief of Engineers for 1873.

2. Tidal conditions. - The 1859 Coast and Geodetic Survey Tide Tables give mean ranges of 6.6 and 6.0 feet at Milford Harbor and Bridgeport respectively. It may be assumed that the mean range at the mouth of Naugatuck River is the average of these figures, or 6.7 feet. The mean ranges in the river are given as 5.5 and 5.0 feet at Stratford and Shelton respectively. It seems likely that the mean ranges were not materially different prior to construction.

3. To determinations of the tidal prism are available, rough approximations computed as the volume required to fill the area up to the sea at Shelton, taking the difference in times of tides and the fresh water flow into account, is 100,000,000 cubic feet inflow and 300,000,000 cubic feet outflow.

4. A rough check on the volume of the outflow may be made as follows: The 1873-report gives a maximum ebb velocity in the main channel east of Milford Beach of 5.23 feet per second, observed on a day when the tide had about its mean range. Comparison between channel velocities

and average velocities for the cross section was made from available data for a similar shaped cross section at Eastport. This comparison indicated that the average velocity for the cross section was about 70 per cent of the channel velocity. By applying this factor to the channel velocity of the Kennebec River a mean velocity of 3.7 feet per second at the strength of the ebb is derived. This velocity would be the maximum ordinate of the current curve for the cross section. As the current curve approximates a sine curve its average ordinate should be about 46 per cent of its maximum ordinate. The average velocity throughout the ebb period, and for the entire cross section was therefore about 2.4 feet per second. The cross-section area at mean tide level as determined from the 1872 survey was about 3,200 square feet. Using 23,000 seconds as the duration of the ebb, the total outflow would be about 510,000,000 cubic feet. The past and recent Survey Current Tables give an average velocity at strength of flood and ebb currents of 2.5 knots, equivalent to 4.2 feet per second. Applying the same method a mean volume of inflow and outflow of 1,000,000,000 cubic feet is obtained.

5. The cross-section area west of Wilford Point at half-tide level was 3,200 square feet as determined from the 1872 survey, and 7,600 square feet as determined from recent examinations. In the period from 1872 to 1927, the width of the gorge was reduced by relocations of the point from about 1,400 feet to 1,100 feet.

6. Dredging prior to construction. - As shown by the 1872 survey, the following depths existed outside the gorge opposite Milford Point. For the inner 4,000 feet there was a definite channel with depths of 6 to 8 feet and widths 60 to 400 feet. The outer bar with depths of 4 and 5 feet was 700 feet wide between the 6-foot contours and about 2,000 feet between 7-foot contours. The project channel dimensions adopted in 1871 and 1888 were 7 feet by 200 feet at the mouth, thence 7 feet by 100 feet through the bars to the river.

7. A pile of rocks known as the "Ballast," located in the channel west of Milford Point was removed in September, 1873. Its volume was 2,216 cubic yards. The first recorded dredging of the outer bar was done in 1835 free of expense to the United States by private interests to secure material for oyster beds. By this means a channel 35 feet wide, 1000 feet long, and 7 feet deep at mean low water was secured, 14,311 cubic yards of sand, gravel, and shells having been removed between July and September, 1835. The same interests removed 37,424 cubic yards between June and August, 1836, and secured a channel 70 feet wide and 3 feet deep at mean low water. The costs of this work to the private interests is not stated. In 1837 it was reported that the outer end of the channel had shoaled to about 7 feet, and in 1839 that the available depth was from 5 to 6 feet.

9. Jetty construction and changes in plans. - The project for the jetty at the mouth of the Neosho River was adopted in 1906. The shoreward 3,250 feet were to be built up to 3 feet above mean low water with top width of 6 feet and side slopes of 1 on 1. The outer 2,500 feet were to be built up to 6 feet above mean high water with top width of 12 feet, outer slope of 1 on 2 and inner slope of 1 on 1. The total length of 5,750 feet was intended to reach the 12-foot contour.

10. The inner 3,250 feet of the jetty were built to project dimensions. The outer arm as completed in 1905 was built to a height of only 4 feet above mean high water with top width of 5 feet. The jetty was extended to a total length of 5,321 feet, or 71 feet farther than originally contemplated.

10a. In June, 1906, the inshore end of the jetty was extended about 35 feet in onto the beach to check the shifting of the sand.

11. From 1912 to 1914 the outer arm was enlarged in cross section. It was built up to 6 feet above mean high water with top width of 6 feet, outer slope of 1 on 1-1/2 and inner slope of 1 on 1. The outer arm is therefore of project height. Yet the completion of the top width and outer slope to project dimensions has not been required to secure a stable structure.

12. The following tables summarize the operations on the construction, enlargement and maintenance of the jetty.

13. Summary of jetty construction. -

Date	Quantity laid (in long tons)	Unit rise	Length Completed (feet)	Remarks
July-Nov. 1892;				
Aug.-June 1890;	5,063	1.49	1,200	Height 3' above mean low water.
July-Dec. 1890;	7,143	1.49	3,250	(3250' = 3' above mean low water. 15' = 4' above mean high water.)
July 1891 to May 1892;	17,150	1.23	4,572	(Outer 1322' = 4' above mean high water. Top width 5').
Oct.-Dec. 1892;	3,300	1.12	4,740	"
Aug.-Dec. 1893;	5,482	1.12	5,025	"
Mar.-Sept. 1895;	13,907	1.09	5,821	"
June 1906	not given	not given	5,856	Inshore end extended onto beach.

Marine Jetty Cross Section - Water Area

Date	Quantity laid	Unit rise	Remarks
<u>Long tons</u>			
Oct. 1912-June 1913;			(1115 ft. measured from outer end built to 6 ft. above mean high water, top width 8 ft., slope on easterly side 1 on 1-1/2).
Mar.-May 1913;	7,302	1.39	
December 1913;			(Outer arm completed to about 6 ft. above mean high water, top width 6 ft., outer slope 1 on 1-1/2, inner slope 1 on 1.
April to July 1914;	7,073	1.63	(Total cost \$12,172.70.)

13. Jetty Maintenance			
Date	Quantity placed	Unit Price	Remarks
July-Aug. 1928	2,654 cu. yds.	.52 per cu. yd.	Near shore end
Fiscal Year 1930	not given	not given	Slight repairs about 500 feet from shore
December 1935	736 tons	.41.33 per ton	Near shore end
March-May 1937	6,652 tons	1.11 per ton	
April 1938	400 tons	not given	Mostly on outer 300'
Spring 1938	1,406 tons	1.50 per ton)	(Inner arm 2,000 tons
" "	1,692 tons	1.00 per ton)	(Outer arm 1,100 tons
" "	162 tons	.50 per ton	Replacing old stone outer portion.
June-July 1938	302 tons	not given	Includes inshore ex- tension - new work
March-June 1941	1,114 tons	1.27 per long ton	710 ft. of outer arm
August 1943	406 long tons	Hired plant & labor (Inner arm (\$1,228.78 total cost	
Sept.-Oct. 1944	595 long tons	Hired plant & labor Inner arm - cost 1,425.75	
October 1945	420 long tons	1.21 per long ton Outer arm - cost \$C1.57	
July-August 1955	3,986 long tons	2.39 per long ton Outer arm - cost \$2,060.41	

The jetty sustained considerable damage during the September 21, 1950, hurricane. It is estimated that 1,300 long tons of stone would be required at this time to restore it to its former dimensions.

15. Original and maintenance costs of jetty. - The original cost of the jetty as completed in reduced section in 1895 was about \$70,000, and as completed in 1911 to present dimensions was about \$95,000. About \$6,000 was spent for repairs on the inner arm prior to completion of the jetty in reduced section in 1895, and about \$20,000 additional prior to completion of its enlargement in 1911. If the latter amount about half was spent on the inner and half on the outer arm. The average annual cost of maintenance on the jetty from 1895 to 1911 was therefore about \$1,000. The annual costs per linear foot were about 16 cents on the inner and 20 cents on the outer arm. However, the outer arm had not been fully maintained by these repairs, so that part of the cost of enlargement in 1911 - 14 should be added to the maintenance for the 1895 - 1911 period. The cost of jetty maintenance since its enlargement in 1911 to 1935 was about \$11,000, all of which was on the outer arm, or an average annual cost of \$670 equal to about 36 cents per linear foot. That the average annual cost of maintenance of the outer arm was not reduced by the enlargement of its cross section in 1911 can be explained by the fact that the outer arm had not been fully maintained over the period from 1895 to 1911.

16. reaching subsequent to construction. - The construction of the jetty up to the spring of 1892 just about reached to the outer bar.

Apparently this construction had little if any beneficial effect on the channel through the bar, as in that year the depth is reported as about 6 feet, but the channel had shifted so as to have the entrance crooked. Whether the completion of the jetty would have caused scouring of the channel cannot be determined, because during July and August, 1892, 13,300 cubic yards of sand were removed at 2 $\frac{1}{2}$ cents from the crest of the bar, making a depth of 7 feet at mean low water in a channel 132 feet wide and about 1,300 feet long. In June to August, 1893, dredging was done at an hourly rate of \$14.50. A channel 75 feet wide, 7 feet deep, and about 1,600 feet long was secured. The total yardage removed under the contract was 19,763, at an average cost of 22 cents per cubic yard. In 1895 a depth of about 6 feet was reported. From June to August, 1896, 20,121 cubic yards were removed from the outer bar at 17 $\frac{3}{4}$ cents per cubic yard making the channel 7 feet deep and 100 feet wide.

17. The jetty completed to full length in 1895 appears to have afforded protection to the dredged channel. An examination in June, 1897, showed only one small place where the depths were less than 7 feet. The minimum depth at that place was 5.5 feet, but only for a very short distance. The next dredging was in June, 1898, when 5,832 cubic yards were removed at 25 cents per cubic yard, by which full dimensions were restored. The outer bar channel was redredged between July and November, 1904, during which period 7,749 cubic yards were removed at 20 cents. The western

half of the channel was dredged from 1 to 3 feet more than project depth to provide for subsequent filling.

18. Mary Anne Bar, which had formed to the southwest of Milford Point was also dredged between July and November, 1904. Under the contract 1,753 cubic yards were removed at 18 cents per cubic yard. During the following winter, Mary Anne Bar shoaled again, and in May, 1905, 3,526 cubic yards were removed at 30 cents per cubic yard. A channel 7 feet deep and 50 to 75 feet wide was thus secured. Mary Anne Bar was dredged again between July and November, 1906, 5,539 cubic yards being removed at 16 cents. In 1907, 16 cubic yards were removed from this bar.

19. Private dredging under permit to secure material for oyster culture during the period May to August, 1906, resulted in deepening and widening the channel west of the jetty. A total of 145,440 cubic yards were removed forming a channel about 2,000 feet long and 400 feet wide with depths of 8 to 20 feet. The cost of this work is not given. However, this channel did not cross the outer bar. Some material was removed from its seaward half, but the greatest depth was dredged where the depth was naturally greater near the bend in the jetty.

20. No dredging has been done on the outer bar since 1906, nor on Mary Anne Bar since 1907. An examination of these bars in 1938 shows the

following conditions. Over the outer bar a channel 300 to 350 feet wide had depths of 7 feet or greater. The controlling depth was about 3 feet. The outer end of the channel had shifted eastward close to the end of the jetty. An area 300 feet long with maximum width of 150 feet on the west side of the dredged channel opposite the end of the jetty had shoaled to depths between 6 and 7 feet.

21. The western half of the channel at Mary Anne Bar for a length about 1,000 feet had depths of 4 to 7 feet. A channel over this bar was partly eastward of the old channel location with widths of 50 to 100 feet and depths of 7 to 8 feet.

22. Channel dimensions of 18 feet by 300 feet from the mouth on the river for about 1 miles were adopted in 1930, but the required local cooperation has not been forthcoming and no work has been done toward increasing the width of the channel.

23. Changes in offshore contours have been added to drawing R. 17 to 26. The following table summarizes the dredging at the entrance to the Neusconic River outside the gorge west of Milford Point. As far as has been determined all spoil from this dredging was used on oyster beds or dumped in deep water in Long Island Sound. None was dumped where it would have any influence on the depths immediately east or west of the jetty. An airphoto oblique view of Neusconic River is included as Plate 7.

date	Summary of dredging operations			Remarks
	Volume Cu.Yds.	Rate per cu.yd.	Channel Se- cured (Feet)	
<u>The Ballast</u>				
July-Sept. 1895	14,374	not known	7 x 35	by private interests.
June-Aug. 1896	57,494	"	9 x 70	"
July-Aug. 1896	16,300	12-1/2¢	7 x 132	"
June-Aug. 1896	19,769	22¢	9 x 75	hourly rate \$18.50 - aver- age cost 22¢ per cu. yd.
June-Aug. 1896	25,124	12-3/4¢	9 x 100	"
June 1903	5,352	25¢	--	Report states full dimen- sions were restored.
June-Nov. 1904	7,710	20¢	7 ⁰ to 10 ⁰ depths	"
May-Aug. 1906	24,500	not given	depths of 8 to 20 feet over a channel 100 feet wide dredged by private interests.	"
<u>The Ballast</u>				
September 1873	4,200	not given	7 x 150	"
<u>The Army Corp</u>				
July-Nov. 1904	1,750	18¢	7 x 100	"
May 1905	3,526	30¢	7 x 50 to 75	"
July-Nov. 1906	5,559	16¢	7 x 100	"
1907	164	17¢	7 x 100	"

The Conclusions. - A study of the dredging records and depth reports reveals that the channel secured by private interests in 1895 and 1896 by

the removal of about 52,000 cubic yards shoaled considerably by 1893, and that 50,000 cubic yards were removed in 1892 and 1893 to obtain a channel of a little greater width. It seems probable that annual dredging of about 5,000 cubic yards over this 7-year period, at a cost of about \$1,200 per annum would have maintained as good a channel. This work could have been done in connection with maintenance at other river bars and thus the price would probably have been low for the small quantity. If the channel could have been maintained at this cost over this period before the jetty was completed, it is reasonable to assume that subsequent maintenance without a jetty would not have exceeded about \$2,000 annually.

15. The total cost of the jetty including maintenance until its completion in 1914 was about \$120,000. At 5-1/2 per cent interest and including 670 annual jetty maintenance since completion, the annual costs, not including depreciation or obsolescence, would be about \$4,700. On the same basis, annual costs on the lighter jetty from 1895 to 1914 were about \$3,700. Although the jetty has afforded sufficient protection so that no dredging has been required to maintain a 7-foot by 200-foot channel since 1906, it seems probable that the same channel could have been maintained at lower annual cost without the jetty by dredging alone. If the greater project depth of 13 feet were assured its maintenance by dredging alone would be much higher, whereas the existing jetty would operate against shoaling of the deeper channel, and its degree of effectiveness would have a much higher evaluation in comparison with maintenance dredging costs of the deeper channel. However, in addition to its value as a jetty, this structure has served as a breakwater and afforded a refuge for small craft. It has also served to fix in one place the entrance channel to the river.

Bridgeport Harbor, Connecticut

Outer Harbor

1. Conditions prior to construction. - A map of Bridgeport Harbor made in 1857 by the Coast Survey is said to show a depth of 5 feet at mean low water on the outer and inner bars. In 8-foot by 60-foot channel, about 1,000 feet long, dredged over the outer bar in 1853 was said to have been secured to 12 feet deep in September, 1853, but a later report doubts the accuracy of this statement.

2. A report dated December 11, 1852, is printed with the documents accompanying the President's annual message in 1853, but is not on hand in this office. In 1852 the channel over the outer bar is said to have been 6 feet deep and 30 feet wide, and that over the inner bar was the same as in 1857. Both the inner and outer bars were dredged in 1853 - 500 cubic yards removed were 8 to 13 feet. The channel over the outer bar was made 60 feet wide and that over the inner bar 100 feet. If the 10,000 cubic yards removed from the outer bar to secure depths of 8 to 13 feet, that removed between the depths of 6 and 8 feet should be regarded as maintenance. Possibly it amounted to half the total volume, or accounted for about \$3,000 of the expenditures. Probably the average annual cost of maintenance of the 15-year period did not exceed \$150, although possibly a greater expenditure would have been required to actually maintain the perfect channel.

3. Surveys of the harbor were made in 1866 and 1868. From those surveys it was reported that the channel was "essentially the same as after the excavation." However, after a survey in 1871, it was reported that depths on the outer and inner bars were little different than before dredging in 1857, but a later report states that the 1871 survey was very inaccurate. All the 1871 dredging should probably be regarded as maintenance, and to actually maintain the channel to the dimensions secured in 1851, may have required the removal of a similar quantity at one or more intervening times over the period. The average annual maintenance over the period 1851 to 1871 was therefore at least 200. A summary of the work prior to 1879 is given in Annual Report of the Chief of Engineers for 1879, Appendix C, pages 350 - 354.

4. Tidal conditions. - No determination of the tidal prism prior to construction is available. The mean range of tide given in the Coast and Geodetic Survey Tide Tables for 1939 is 6.6 feet. The surface area of Pinnevert Harbor and tributaries to the end of the jetties is about 32,000,000 square feet. If it is assumed that the range of tide over the entire area averages 6.6 feet, the tidal prism would be about 350,000,000 cubic feet. The cross-section area of the gorge between the jetties, as taken from the 1933 survey and corrected by the 1936 channel examination, is about 21,500 square feet at half-tide level. The 1933 Coast and Geodetic

Survey Current Tables give a mean flood and ebb current velocity between the jetties of 0.7 knot. By assuming a flood and ebb current of equal duration, reducing the value given to mean for the cross section by a factor of 70 per cent, and to a mean for the duration of flood or ebb by a factor of 64 per cent, a value of 260,000,000 cubic feet is derived. These rough approximations indicate that the volume of the tidal prism is in the neighborhood of 300,000,000 cubic feet inflow and outflow per tidal cycle. The volume of fresh water discharge is negligible. Possibly the smaller figure derived by the latter method may partly be accounted for by loss through the jetties and through the opening at the inner end of the west jetty.

5. Jetty construction. -

Site	Quantity	Unit	Length	Total	
				Long Tons	Price, plated (Feet)
<u>West Jetty</u>					
All 1971	3,924	cubic ft.	321	Triangular section 9 or 11 foot ; above mean low water - 45° slopes.	
Fiscal Year 1973	0,523	cubic ft.	1,371		
July-West. 1900	5,031	cubic ft.	2,000		
July 1907 to Jan / 1908	43,559	cubic ft.	1,171	(Height 9.5' above mean low water. Top width 8'. Outer slope 2 on 5. Inner slope 1 on 1.	
March-May 1908					

Date	Quantity	Unit	Length	Fees:	
				Long Term Price	Term
				Short term	selected
(Feet)					
					<u>West Jetty</u>
September, 1900	39,271	ft.	14.17	2,110	Same cross section as East Jetty except top width = 6 feet.

The total costs, including Government expenses, were about \$100,000 for the east jetty and \$50,000 for the west jetty.

6. Summary of dredging operations on Outer and Inner Bars -

Date	Quantities - Cu. Yds.	Unit	Rise Channel	Remarks	
				Outer Bar	Inner Bar
(Feet)					
					<u>Prior to Construction of Jetties</u>
1858					
	not given	-	said to be 3 x 60	3 to 13	About 40,000
			72.64		expanded.
August 1853 to June 1854					
	10,093	ft.	16.756	30x	(Widths: Outer, (100'; inner, 60').
July to Aug. 1871					
	5,020	ft.	10,260	25x46	Outer bar
					Inner bar
<u>West Jetty with 1,300 Feet of East Jetty</u>					
May-July 1873					
	5,513	ft.	11,532	12-7/8x	10 x 150
					, x 200
Fall 1873					
	-		30,319	10x	10-13 x 100; Inner bar
Fall 1874 and Spring 1875					
	36,613	ft.	36,136	14-1/2x	9 x 350
					, x 450
					Inner bar

site	quantities - Cu. Yds.	unit prices	channel	remarks
	Outer Bar Inner Bar for 10, 12, 14, Dimensions			
<u>12-Foot Project with 1,300 Feet of East Jetty</u>				
July to Dec. 1875	34,913	-	16¢	12x105 Outer bar
" " "	"	17,624	15¢	12x105 Inner bar
April-May 1879	13,682	-	11¢	12x160 Outer bar
Sept.-Oct. 1879	26,380	-	15¢	12x200 Both bars
Oct.-Nov. 1880	"	"	"	12x200-12x105 Outer bar
June 1881	21,290	-	20¢	12x300 Outer to inner beacons
<u>10-Foot project with 1,300 Feet of East Jetty</u>				
November 1871	Below Lower Beacon		"	"
March-June 1875	40,450	11-1/2¢	12x100	Outer end 2,750'
Jan.-March 1876	21,523	"	12x160-80	Inner end 2,000'
Aug.-Oct. 1877	"	"	"	"
December 1877	137,700	10¢	12x220	To inner beacon-
Jan.-June 1878	"	"	"	5,000 feet.
<u>10-Foot project with 1,750 Feet of East Jetty</u>				
Jan.-June 1881	40,756	3-1/2¢	10	directly in vic. of outer beacon
Fiscal Year 1883	48,964	3-1/2¢	12x150	1/2 mile completed
Fiscal Year 1884	179,166	3-1/2¢	12x200	Completed inner 3,700 feet
Fiscal Year 1887	37,366	12.2¢	12x200-825 remainder	"
				" plotted

Date	Quantities	Unit Price	Channel:		Remarks
			Cu. Yds.	per Cu. Yd.	
<u>22-foot project with completed jetties</u>					
April - June 1909 Fiscal Year 1910	114,923	12-1/3\$	22 x 300		These figures include 36,579 cu. yds. overdepth.
	260,436	12-1/2\$			
<u>25-foot project with completed jetties</u>					
Aug. 1932 to Sept. 1933	592,741	12.75\$	25 x 300		Total cost 11.53\$ per cubic yard.

Part of the spoil from the 1932 - 33 dredging was pumped onto marsh land north of Lewis Gut and east of White Rock Creek. A small volume was deposited on an area about 200 feet by 1,200 feet along the inside of the east jetty seaward of the bend. This area was raised to about 1 foot above mean low water. As far as is known all other spoil was dumped in deep water in Long Island Sound.

7. The 1973 dredging provided a channel 9 feet by 110 feet over the outer bar and 3 feet by 350 feet over the inner bar, and presumably was practically all new work. The 1974 - 75 dredging was directed toward further widening the 9-foot channel. The dredging of a 12-foot channel in the latter half of 1975 followed so closely on the completion of the 9-foot channel that no opportunity was afforded to observe what the maintenance costs of the 12-foot channel would have been.

9. An examination of the channels was made in October, 1895. The 12-foot channel over the outer bar was 75 feet wide, but the width between 11-foot contours was over 200 feet. The channel over the inner bar was 300 feet or more in width. A survey made in October, 1894, before dredging showed that practically full width and depth existed over the inner bar. Over the outer bar the distance between 12-foot contours was about 220 to 250 feet. Throughout the 13-year period from 1881 to 1894, no work was done on the outer and inner bars. Apparently the 1320-foot jetty had been effective in preventing shoaling due to the westward littoral drift. The widths over the outer bar between the 12-foot contours was slightly greater in 1894 than were reported to have been dredged in 1880 - 81. It appears that the 12-foot project was practically self-maintaining with a jetty 1,320 feet in length.

10. The dredging of a channel 15 feet deep and 220 feet wide was completed in 1896. Work on the 15-foot by 300-foot project, started in 1891 and completed in 1897, followed so closely after the completion of the 15-foot channel that it could not be determined whether the 15-foot channel would have been self-maintaining. Neither could the effect on these channels of the east and west jetties, completed in 1898, be observed.

11. The 15-foot by 300-foot project was in effect for only one year when the 12-foot by 300-foot project replaced it. The latter channel was

dredged in 1909 and 1910. An opportunity to observe the shoaling of the 22-foot channel was afforded, however, as work on another increase in depth was not begun until 1932. No maintenance dredging was done on the 22-foot by 300-foot channel outside of the inner beacon during the 22-year period. An examination made in September, 1932, showed that there had been slight shoaling along the edges of the 22-foot by 300-foot channel between the inner beacon and the outer end of the jetties. The self-maintenance of this channel can clearly be attributed to the two jetties. Outside of the jetties the channel had been dredged a distance of about 5,000 feet to the 22-foot contour. While this section of the channel was unprotected, the shoaling was not extensive. From a point about 500 feet beyond the jetties, for a distance of about 1,000 feet, the average depth was about 21.5 feet. Beyond that section there was slight shoaling along the edges of the channel. As the 1910 dredging had assured an overdepth averaging about 1/2 foot, the shoaling of the channel area may be assumed to have averaged about 1 foot over the 22-year period 1910 - 1932. This would amount to about 100,000 cubic yards, and cost when removed in 1932 - 33 about \$11,000, or an average cost of \$650 over the 22 years. Since the 25-foot channel was completed in 1933, there has been no maintenance thereto.

11. Available data on changes in offshore contours have been added to drawing P. A. 4. No. 265. The older maps available do not show hydrography far beyond the present ends of the jetties, and more recent map shows depths only in the immediate vicinity of the channel. A airplanes oblique view of Bridgeport Harbor is included as Plate 9.

12. Jetty Maintenance. -

Date	Quantity Long Tons	Unit Price, Jetties	Remarks
July-Sept. 1900	not given	\$2.00	most repairs and extended under same contract.
Fiscal Year 1921	" "	not given	Total cost \$7,579.73
July-August 1935	(2,435 1,047)	2.09 2.09	(East) Total cost \$11,472.23 - average (West) \$3.13 per long ton.

The division of cost on the 1900 work between repairs to the old east jetty and new work extending it is not given. The cost of these repairs probably did not exceed \$1,000, or at an average annual rate of about 40 since its completion in 1873. Since the completion of both jetties in 1908, the total maintenance costs have been about \$9,300 on the east and \$10,400 on the west breakwater. The average annual costs for the east and west jetties over the 27-year period from 1908 to 1935 have been about \$30 and \$60, or 3 and 19 cents per linear foot respectively. During the October 21, 1938, hurricane extensive damage was done to both jetties. It is estimated that about 2,300 long tons of stone for the east and 50 long tons for the west jetty would be required to restore them to their former condition.

13. Annual Costs. - The following table summarizes annual costs for the various entrance channel projects as determined from best available data. Interest has been computed at 3-1/2 per cent. Depreciation and obsolescence has not been included.

Period (years)	End Year	Jetty Length	Status	Annual Costs			Avg. Jetty Main	Total
				Main Dredging	Jetty Interest	Avg. Jetty Main		
1853-1855	8	none		3150	-	-		3150
1855-1871	8-13	"		200	-	-		200
1871-1873; 12-13; 1300' S	(1)	none		1220 (1)		40		1260
1881-1894	12	"		1220		40		1260
1898-1901	15	" (2)		1220 (3)		40		1260
1907-1909	16	Both com- pleted		12 3500 1750	18 340 (1) 400	340 (1) 400		3240 2150
1910-1912	17	"		650	none	340 400		640 600
1933-	25	"	None to date	none		340 400		5990

(1) At end of period.

(2) 1760 feet of east jetty completed at end of period.

(3) 1550 at end of period.

11. Conclusions. - Whether the various entrance channels dredged in Bridgeport Harbor could have been maintained more economically by dredging alone cannot be determined. A comparison of the total annual costs of the projects may afford some indication of the economic justification of the jetties. By comparing total costs before and after the construction of the 1,300-foot east jetty, the increase in annual charges due to the jetty appears to be about \$1,000, sufficient to remove about

5,000 cubic yards annually. Possibly the 9-foot and 12-foot channels could have been maintained by this volume of dredging.

15. After completion of both jetties in 1908, the annual costs on the 12-foot project were increased about \$2,600 by the east jetty and \$2150 additional by the west jetty. The small amount of shoaling experienced in the channels dredged beyond the outer limits of the jetties indicates that the volume of sand movement in deep water is small. It seems probable that the short original portion of the jetty accomplished more in protecting the channels than the extension into deeper water completed in 1908. While the jetties have undoubtedly been very successful in accomplishing their purpose, it is possible that the extension of the east one in 1907 - 08 was not economical. In view of the predominance of the westward littoral drift and the more resistant character of the shore material immediately west of the entrance, it seems quite probable that the additional dredging that would have been required without the east jetty could have been done at less than its annual costs of \$2,150. However, in addition to the value of these structures as jetties, they have been of service as breakwaters in providing protection of the harbor against wave action. The breakwater value of this combined breakwater-jetty construction, on this coast where severe storms are frequent, is considered of such benefit to navigation as to amply justify these structures.

Southport Harbor, Connecticut

1. Conditions prior to construction. - The Annual Report of the Chief of Engineers for 1871, Appendix I, pages 423 to 528, contains available information on conditions prior to construction in 1829 to 1832 and on the work done to 1871.

2. Tidal conditions. - No determination of the tidal prism prior to construction is available. The half-tide level cross-section area of the gorge at that time must have been little more than half its present area. The greatest depth at mean low water was then about 2 feet, and is now about 10 feet. The half-tide level cross-section area in 1935 was about 2,000 square feet. As to the former smaller cross section, there would have been less tidal range at the head of the estuary, and less tidal prism. On the other hand, the surface area was reduced considerably by bulkheading and filling some marsh area in 1916 - 17. The data available is insufficient to estimate the effects of these changes on the tidal prism.

The mean range of tide in this section of Long Island Sound is about 6-7 feet. The range near head of tide is probably little different. The surface area of the estuary taken from the 1935 survey was about 2,000,000 square feet. The present tidal prism would therefore be about 13,000,000 cubic feet inflow and outflow per tidal cycle.

3. Jetty construction. - Plans and specifications of the original jetty construction are described in report of 1871 as noted in first paragraph. Recommendations for an increase in height are given in the same

report. The jetty was repaired and raised in 1875 and 1876. The cost of the jetty and its enlargement was about \$15,000. A historical summary of the improvement is given in the Annual Report of the Chief of Engineers for 1879, Appendix I, pages 355 - 357.

4. Dredging. - In connection with the original jetty construction a small amount of material was removed by oars, scyphers and by hand with shovels. Apparently the depth obtained was only 2 feet at mean low water. This channel was self-maintaining. The same depth was reported when the 1-foot project was proposed.

In 1876 - 77 a 4-foot by 60-foot channel was dredged from the outer beacon to above the end of the jetty, a distance of about 2,000 feet. Some of the soil (651 cubic yards) was deposited in vacant spaces between the walls of the dike and the remainder dumped in deep water outside the harbor. The unit price on the former was 37 cents per cubic yard, and on the latter 17 cents. The volume removed was 17,519 cubic yards.

In March and April, 1881, dredging was done from the outer end of the jetty to within 100 feet of the wharves. A channel 4 feet by 50 feet was secured by the removal of 11,234 cubic yards at 19 cents. As the channel west of the jetty had previously been dredged to larger dimensions, some of this work must have been maintenance, but the division is unknown.

In July and August, 1881, 6,760 cubic yards were removed at 33 cents from near the end of the jetty out to the 1-foot contour. The 1-foot

channel was widened to 95 feet. As the report indicated little shoaling of the previous 4-foot channel, practically all this dredging was now waste.

In April and May, 1893, dredging was done in the upper harbor and some widening west of the jetty.

The section of the 4-foot channel west of the jetty secured from 1876 - 83 proved to be practically self-maintaining. The edges shoaled from 1 to 2 feet, but through the center of the channel depths averaged about 5 feet, as shown by the 1896 examination. No maintenance dredging had been done in this period. The channel over the outer bar beyond the end of the jetty had shoaled about .5 feet and had narrowed somewhat.

The 6-foot project adopted in 1902 was secured by dredging from 1903 to 1906. A survey made in November, 1910, revealed that the channel over the outer bar beyond the end of the jetty had shoaled. The controlling depth at mean low water was about 4 feet. The general depth was in excess of 7 feet and the minimum width between 3-foot contours was about 100 feet. Along the jetty the dredged depths had been well maintained by tidal action. Depths of 6 to 8 feet existed over a minimum width of about 70 feet. The channel at the entrance to the harbor was restored to project dimensions in 1913 - 14 by the removal of 27,436 cubic yards at \$1-1/2 cents.

In 1916 and 1917, for land reclamation, the Fairfield Country Club dredged 390,234 cubic yards from the channel west of the jetty and

dikes, and from an area east of the channel to a maximum distance of about 1,000 feet out beyond the end of the jetty. So dredging was done on the outer bar beyond that point. Depths of 20 to 30 feet were dredged in some areas. An examination was made in June, 1927. Over the outer bar where private interests had done no dredging, the 6-foot channel had maintained itself with widths of 50 to 100 feet. Along the line of the channel, between the outer bar and the end of the jetty, depths varied from about 7 to 22 feet, but were mostly over 15 feet. Out of the outer end of the jetty depths were from 20 to 30 feet for a length of about 500 feet. For the next 500 feet depths were from 10 to 15 feet and opposite the inner 500 feet of jetty they averaged about 9 feet.

Between 1922 and 1925, the local yacht club spent about \$50,000 in removing isolated shoals along the edges of the channel, and in widening and deepening the entrance channel over the outer bar to dimensions of 3 feet by 100 feet.

By 1926 the outer channel had shoaled an average of less than 1 foot for a distance of about 500 feet. In the area south of the end of the jetty where depths of about 15 feet had been dredged, depths were about 12 feet. Out of the jetty depths of 20 to 30 feet had shoaled to 12 to 17 feet, depths of 10 to 15 feet had shoaled to 8 to 11 feet, and depths of 3 feet had shoaled about 1 foot.

A project for a 3-foot by 100-foot channel was adopted in 1925.

As a channel of greater dimensions over the outer bar and west of the jetty had already been secured, the dredging in these areas to a depth of 9 feet should be considered as maintenance. About 2 feet oversdepth was secured by the 1925 - 36 dredging. The volume of material removed above elevation +9 feet was 6,977 cubic yards on the outer bar and 17,444 cubic yards west of the jetty. The maintenance cost on the outer bar was therefore about \$2,600 and west of the jetty about \$6,500.

Changes in offshore contours are shown on accompanying drawing R. & H. No. 278, which is submitted to supplement drawing R. & H. No. 268 forwarded with previous report. An airplane oblique view of Southport Harbor is included as Plate 9.

A summary of dredging operations is given in the following table:

Date	Volume Cubic Yds.	Unit Price	Channel Dimensions	Remarks
1829 - 1837	not given	not given	2-foot Project 2 feet	
1876 - 1877	17,319	17 cents	4' x 60'	2-foot contour to near inner end jetty. (mostly new work in river.)
March - April 1881	11,234	19 cents	4' x 50'	(Probably some maintenance (west of jetty.)
July-August 1881	5,768	33 "	4' x 35'	Mostly new work outside jetty.
April - May 1883	3,390	32 "	4 feet	Mostly in upper harbor
May - June 1903	about 25,000	26-1/2¢	6' x 75' to 100'	
July-August 1903	1,471	not given	-	
Sept. 1905-Feb. 1906	22,036	26¢	6' x 75'	Mostly upper harbor. In- cludes 561 cu. yds. main- tenance.
August-Sept. 1906	11.1	not given	-	
Aug. 1913 to Feb. 1914	43,313	26-1/2¢	6' x 100'; 27,436 cu. yds. from en- trance channel	

Site	Volume	Unit	Channel	
	cu. Yds.	rice	Dimensions	
<u>Private dredging</u>				
1916 - 1917	390,294	not given	-	Cost about \$200,000.
1922 - 1925	not given	not given	9 feet	Cost about \$20,000.
<u>2-foot project</u>				
1925-1935-March 1936	112,973	34.84	9' x 100'	} Cost \$53,000.
		Back 723	34.00	}

Practically all spoil was dumped in deep water in Long Island Sound, except that dredged by the Fairfield Country Club in 1916 - 17, which was used to reclaim marsh land north of Hamile's Beach and east of the dike.

5. Annual costs of maintenance dredging. - The numerous changes in the project dimensions make it difficult to determine the maintenance costs on each project channel. In the 2-foot project no dredging is reported over a period of about 10 years, and little dredging is reported at the end of that time. Therefore the 2-foot project can be regarded as practically self-maintaining.

The 4-foot project has shoaled somewhat by 1903, practically all of which was beyond the end of the jetty. It is estimated that 5,700 cubic yards of the 1903 dredging could be classified as maintenance on this project. The cost of this volume was about \$1,050, or about \$20 per cu.yd. over the 26-year period 1877 to 1903.

The 6-foot entrance channel accrued in 1903 shoaled by 1914, when it is reported that the removal of 27,436 cubic yards was required. The

cost of this work was about \$7,000, or at a rate of about \$650 per annum. As the overdepth on this work averaged about 1 foot, this figure is probably high.

The 3-foot channel was secured partly in 1917 and partly by 1925. In the outer bar channel the maintenance was \$2,600 over the 11-year period 1925 to 1936, or about \$240 per annum. Out of the jetty the costs were \$6,500, which may be spread over the period 1917 to 1936 at an annual rate of about \$340. The total for the two areas is about \$580. This figure would probably be considerably higher if private interests had not secured a large amount of overdepth in 1916 - 17.

C. Conclusions. - The annual jetty maintenance since its enlargement in 1875 - 76 has averaged about \$40. The interest charges on \$15,000 original cost at 3-1/2 per cent would be \$525, or with maintenance, a total annual cost of \$565. The channels dredged through the bar beyond the end of the jetty exhibited a far greater degree of permanence than had been expected. It does not seem probable, however, that the same would have been true of a channel just west of Vassilie Beach, if no jetty had been provided. Whether any of the project channels could have been maintained by dredging alone at less cost than the \$565 annual charges on the jetty must remain a matter for conjecture.

On the other hand, the question of whether a longer jetty would be economically justified can probably be determined. To protect the

4-foot channel to the 5-foot contour would have required extension of the jetty by about 1,300 feet. The original cost and annual charges on such an extension would be greater than those of the existing jetty (\$56). The annual charges would therefore be far greater than the average annual maintenance costs by dredging, which have been estimated at \$40.

Similarly, to protect the 6-foot channel would require the extension of the jetty by about 1,300 feet, at a cost of more than 1-1/2 times that of the existing jetty. The annual charges on such an extension would probably be about \$1,000, or about 50 per cent more than the average annual dredging costs.

The figures on the 7-foot project are not sufficiently complete to make as good a comparison, but they indicate that a jetty to the 7-foot contour would be difficult to justify economically.

This existing jetty has also a high value as a breakwater to protect the docks and whars opposite it on the West Shore and boats which tie up there or anchor in the area. The structure is considered very valuable.

Summary

1. The additional data requested primarily concerns the relation of the volume of the tidal prism to the channel dimensions secured and maintained, and the effect of jetties on channel maintenance and annual costs. Tidal prism and channel dimensions are compared in the following table. As Block Island Harbor of Refuge is not a jetty entrance, it has not been included.

Location	Present Channel Width (Feet)	Present Tide Level at Gorge (Feet)	Present Cross Sections at Tide Level (Square Feet)	Present Half-tidal Outflow between High Water and Tide Level at Gorge (Millions of Cubic Feet)	Area to Walls at Tide Level at Gorge (in Acre Feet)	Area to Walls at Tide Level at Gorge (in Acre Feet)
Antoniett	300x15	24.700	610	14,000	1.8	
Block Island front salt end	25x150 13' or over for 300'	3,700	70	1,800	4.8	
Connecticut River Sybrook Jetties	300x15	7,300	200	4,600	2.0	
Hilford	100x10	2,500	50	1,100	2.3	
Cumstonic River	200x7	7,600	500	11,500	0.7	
Ridgeport Main Harbor	300x25	21,300	700	6,900	3.1	
Southport	100x9	2,300	18	400	7.0	

2. The ratio of the present gorge cross-sectional areas to the volume of the outflow per tidal cycle averages about three for these entrances. No of the most satisfactory, front salt pond, Block Island, has

a ratio of 4 to 3. Obviously, Southport with a ratio of 7 has been deepened to an extent out of proportion to the size of the estuary. On the other hand, the outflow of the Connecticut River should maintain a considerably larger channel. If the approved 18-foot by 200-foot channel is dredged at this location, the ratio will be close to unity.

3. In addition to the classifications previously given, the jetties studied in this report may be further classified. Some protect a dredged channel for practically its full length, while others intercept the littoral drift moving close to shore and protect only a portion of the dredged channel. Those at Milford, Bridgeport and Southport Harbors are in the latter class. In these three cases, the unprotected channel seaward of the outer end of the jetties has shoaled less than had been expected. At Milford this can probably be attributed to the protection afforded by Clich's Point. In these three cases, maintenance dredging costs have been lower than estimated annual costs of the extension of even one jetty to the end of the channel. This fact brings up the question as to whether experience with shorter jetties would have been similar at the other locations. Of the four remaining jetty entrances, probably those at Housatonic and Great Salt Pond would have lower total annual costs with shorter jetties, that at Connecticut River lower with no jetty, while at the mouth of the Connecticut River the jetty system seems to be moderate and yield

lower costs than would have obtained without it. In the case of Bridgeport it is possible that the costs would have been lower with a shorter east jetty, and probably lower without the west jetty.

4. Conclusions. - The jetty construction in this District has in general been moderate in extent and cost. In general these studies have indicated that one or two cases of the eight jetty installations constructed in this District may be of doubtful economic justification from the standpoint of the function of channel maintenance.

Jetties have other values than merely that which may be shown by a lessened maintenance cost in comparison with annual or periodic dredging. Jetties fix a channel so that it is known at all times to navigation. Jetties in this District have all been at least partially successful. They have practically always afforded a channel of project depth if not of full width. In cases where the full width was not maintained, the deficiency has been small. Up to these facts jetties have afforded uninterrupted navigation between them. On the other hand, had dredging been relied upon, it is probable that there would have been various of decreased depths where navigation requiring full depth would have been impeded or delayed.

In many cases, as brought out in conclusions to the individual studies, the jetty installation has combined the functions of breakwater protection. It is difficult to evaluate the latter. The harbors of the District are visited with very severe storms annually. Breakwater protection to navigation is consequently of the highest importance. Jetties at Bridgeport, New Haven, Southport, Milford, and the mouth of the Housatonic all fulfill breakwater functions, some to a very importance if not indispensable degree.

It is believed that experimental dredging might profitably be attempted before jetties are constructed. It seems probable, however, that a short jetty on the updrift side of an entrance to intercept some of the littoral drift would be profitable in most cases. Such a jetty, extending from high water line to low water line, or possibly to about the 6-foot contour, would probably intercept a considerable proportion of the sand in motion. As the beach built out the jetty might have to be extended, but possibly in shoaler water than if built at first. Being comparatively low in first cost, the short jetty would probably result in savings in dredging exceeding its annual charges, whereas a longer jetty might not be economic, even though it reduced maintenance dredging to a greater degree. Since frequent changes in the direction of the littoral drift make two jetties necessary, it is even more likely that the shorter jetties would result in lower total annual costs than those extending the full length of the dredged channel.